Proceedings of the 11th international conference on disability, virtual reality and associated technologies (ICDVRAT 2016)

Book

Published Version

The 11th International Conference on

Disability, Virtual Reality and Associated Technologies

Proceedings

Edited by:

Paul Sharkey
Albert 'Skip' Rizzo

20 to 22 September, 2016

Los Angeles, California, USA

ICDVRAT 2016

The papers appearing in this book comprise the proceedings of the 11th International Conference on Disability, Virtual Reality and Associated Technologies, held between the 20th and 22nd of September, 2016 in Los Angeles, California, USA. The papers presented reflect the authors' opinions and are published as presented and without change (formatting and minor editing excepted). Their inclusion in this publication does not necessarily constitute endorsement by the editors, ICDVRAT, or the University of Reading.

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

> Author, AB, Author, CD, and Author, EF (2016), Title of paper, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. *n–m*, Los Angeles, California, USA, 20–22 Sept. 2016.

Proceedings reference number: ISBN 978-0-7049-1547-3

Published by

The University of Reading

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Artwork and Conference Layout by *sckelp*, adapted from original ideas of Eric Phipps and David Angus (both of Project DISCOVER, ICDVRAT Logo) and from original clipart from the CorelDraw Clipart Library (ICDVRAT 2016 Graphic).

Printed in the UK.

Conference Schedule at a Glance

Monday, 20 September, 2016

09:00 – 17:00	Pre-Conference Workshop on Virtual Reality and Pain Management

Tuesday, 20 September, 2016

08:00	Registration/Information Desk opens from 08:00
08:50	Welcome
09:00 – 10:00	Session I: Stroke Rehabilitation
10:00	Coffee
10:30 – 11:30	Keynote: Simon Richir *on* Laval Virtual Vision 2025
11:30 – 12:30	Session II: Neurodisability/Behaviour
12:30	Lunch
14:00 – 15:00	Session III: Interaction
15:00	Coffee
15:30 – 16:50	Session IV: Healthcare Design
18:30	Reception

Wednesday, 21 September, 2016

08:30	Registration/Information Desk opens from 08:30
09:00 – 10:00	Session V: Visual Impairments
10:00	Coffee
10:30 – 12:30	Session VI: Psychology/Communication
12:30	Lunch
13:00	Lunchtime Talk: Roy Taylor, Corporate Vice-President, AMD
14:00 – 14:40	Invited Speaker: Mónica Cameirão *on* Stroke Virtual Rehabilitation
14:40 – 15:10	Short Paper Podium Presentations
15:10 – 16:50	Poster Presentations *&* Interactive Demo Session
15:30	Coffee
c. 20:00	Conference Dinner

Thursday, 22 September, 2016

08:30	Registration/Information Desk opens from 08:30
09:00 – 10:20	Session VII: System Design/Self-management
10:20	Coffee
10:50 – 12:10	Session VIII: Stroke/General Rehabilitation
12:10	[*Conference Closed*]
13:00 – 17:00	Post-Conference Workshop on Virtual Reality and Wounds of War

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Keynote II Mónica Cameirão *on* Stroke Virtual Rehabilitation

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Session I Stroke Rehabilitation

Session II Neurodisability/Behaviour

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Session VII System Design/Self-management

Session VIII Stroke/General Rehabilitation

Short Papers

Internet address references within the papers presented in this volume were accessed and checked to be valid during the week 1–7 August 2016.

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Conference Series Archive

Paul Sharkey, University of Reading, UK

Introduction

The 11th International Conference on Disability, Virtual Reality and Associated Technologies (ICDVRAT 2016) provides a forum for international experts, researchers and user groups to present and review how advances in the general area of Virtual Reality can be used to assist people with Disability.

ICDVRAT is now in its 20th year, with biennial conferences in the series previously held in Maidenhead, UK (1996), Skövde, Sweden (1998), Alghero, Sardinia, Italy (2000), Veszprém, Hungary (2002), Oxford, UK (2004), Esbjerg, Denmark (2006), Maia & Porto, Portugal (2010), Viña del Mar/Valparaíso, Chile (2010), Laval, France (2012), and Gothenburg, Sweden in 2014.

After peer review process, the International Programme Committee selected 30 Full Papers for presentation at the conference, collected into 8 plenary sessions: Stroke Rehabilitation, Neurodisability/Behaviour, Interaction, Healthcare Design, Visual Impairments, Psychology/ Communication, System Design/Self-management, and Stroke/General Rehabilitation. There will be an additional 30 Short Papers presented at a Poster Session. The conference will be held over three days between the 20th and 22nd September at the Millennium Biltmore Hotel in downtown Los Angeles, California, USA.

For the 2016 conference, there will be two invited presentations. The first will be a Keynote Address from Simon Richir of Arts et Metiers Paris Tech and Laval Virtual, introducing the concept of the Laval Virtual Vision 2025, a shared vision of the future of immersive technologies, the main challenges to be overcome and how this might be achieved. The second invited presentation will be from Mónica Cameirão, inaugural recipient of the ISVR Early Career Researcher Award in 2016, who will present a personal reflection on 10 years researching in the area of stroke virtual rehabilitation.

The Conference will host two workshops: a pre-conference workshop, held on Monday, September 19, sponsored by the Mayday Fund, will focus on Virtual Reality and Pain Management, whilst a post conference workshop on the afternoon of Thursday, September 22, will discuss Virtual Reality and Wounds of War.

Abstracts from this conference and full papers from the previous conferences are available online from the conference web site *www.icdvrat.org*.

Acknowledgements

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

On behalf of ICDVRAT 2016, we welcome all delegates to the Conference and sincerely hope that delegates find the conference to be of great interest.

Skip Rizzo and Paul Sharkey

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The main sponsors of ICDVRAT 2016 are:

The University of Reading, UK

USC Insititute for Creative Technologies, USA

University of Southern California, USA

and

The Mayday Fund, USA

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

International Society for Virtual Rehabilitation

Bright Cloud International Corp

Neurobehavior Services Inc.

Additional help in publicising the conference has been gratefully received from vrpsych-l@mymaillists.usc.edu, and the ISVR and VRPSYCH-L facebook pages, amongst many others.

Conference Prizes

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

Bright Cloud International Corp (www.brightcloudint.com) is the 2016 sponsor for Best Full Paper and Best Short Paper awards.

The International Society for Virtual Rehabilitation (www.isvr.org) is the 2016 sponsor for Best Student Full Paper and Best Student Short Paper awards.

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

Hidden Los Angeles

Compiled by Paul Sharkey

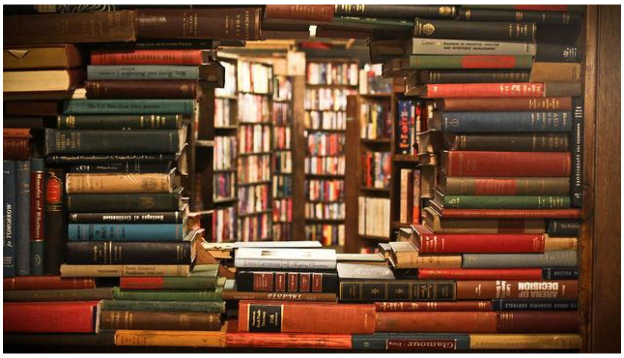
A tradition of this conference series is to include a short essay about the location of the conference, allowing delegates a greater understanding of the historical and cultural developments over the years that shaped the host town or city into what is seen today.

In brief, Downtown Los Angeles has traditionally been seen as the main business and govenermental centre of the wider Los Angeles metropolitan area, and is well known for its parks and theatres, a diverse residential neighbourhood, and perhaps more infamously for its own 'Skid Row'; east of Main Street, Los Angeles' Skid Row is said to have one of the USA's largest stable populations of homeless people (between 3–6,000). In recent years Downtown Los Angeles has been through a resurgence, with once empty but yet intact historical buildings being repurposed, allowing the centre to blossom with new inverstment and increases in residential populations.

However, with a city as expansive and diverse as Los Angeles, the second biggest city in the United States, any short essay would surely be left wanting – an alternative approach is required …

And so, compiled below is but a small selection of the oddities and curiosities available at the Atlas Obscura website, concentrating on the downtown district, centred around Pershing Square, many of which are within comfortable walking distance of the Millennium Biltmore conference hotel. Images and text (edited) are with the kind permission of Atlas Obscura*.

The Last Bookstore 453 S. SPRING STREET

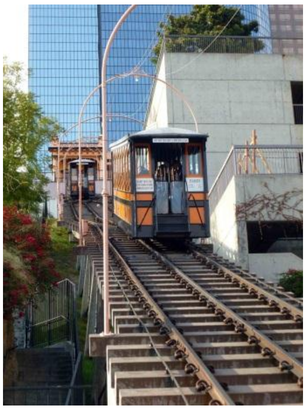




The Last Bookstore is an iconic LA bookstore housed in the grand atrium of what was once a bank. The marble pillars and mile-high ceiling remain from the old bank, but in place of patrons and guarded stacks of cash, bookshelves line the walls and artful displays of books abound. The bookstore specializes in reasonably priced used books, and takes great pride in offering a selection of well-kept vintage books as well. Anyone who's ever loved a vintage book will know exactly what that means for the musty, decadent smell that hangs in the air in this seemingly sacred place (6 minutes walk).

Space Shuttle Endeavour CALIFORNIA SCIENCE CENTER, 700 EXPOSITION PARK DRIVE

The fifth and final space shuttle that NASA built, Endeavour was an orbiter that flew its first mission in 1992. Built to replace the doomed Challenger shuttle after it was lost during launch, Endeavour represented hope and perseverance, a symbol of the bravery displayed by the men and women who persisted in exploring the unknown, despite the strong odds against them (30 mins by cab).

Angels Flight 351 SOUTH HILL STREET



Established in 1901, the historic funicular Angels Flight railway has carried millions of Angelenos up and down the steep incline of Bunker Hill. Though the 315-foot trip only lasts thirty seconds, it is believed that Angels Flight has carried more passengers per mile than any other railway in the world, making it not only the shortest in length, but also the most traveled (6 mins walk).

Bob Baker Marionette Theater 1345 W. 1ST STREET

Bob Baker is an established puppeteer, and with the help of his 3,000 handmade marionettes, has been entertaining audiences for over 70 years. Baker was a key activist in establishing union status for puppeteers, and his theater serves as a training ground for many puppet-makers who go on to work in fantasy films. With a long history of working in Hollywood, Baker's creations have been featured in TV shows such as Star Trek and Bewitched, and films such as Bluebeard, A Star is Born and Close Encounters of the Third Kind (25 minutes walk/4 mins by cab).

Clifton's Cafeteria 648 SOUTH BROADWAY

Clifton's Cafeteria, a cabinet of curiosities, where you can "*Dine for Free Unless Delighted*" (7 mins walk).

*Atlas Obscura. "Definitive guidebook and friendly tour-guide to the world's most wondrous places. Travel tips, articles, strange facts and unique events." http://www.atlasobscura.com

Blurring the lines between digital and physical worlds

Simon Richir

Arts et Metiers ParisTech/Laval Virtual, FRANCE

ABSTRACT

The recent evolution of immersive technologies, such as Virtual Reality (VR) and Augmented Reality (AR) as well as Mixed Reality (MR), leads to the emergence of new immersive experiences occurring in blended spaces constituted of both digital and physical worlds. This paper, based on the outcomes of the first edition of the Laval Virtual Seminar on Vision 2025, explores Immersive Virtual Environments (IVE), its related technologies, and more particularly addresses the potential increase of the immersion quality. It also discusses the main IVE elements and tries to foresee their key challenges and needs towards envisioned future developments.

BIO-SKETCH

Simon Richir, M.Eng, Ph.D., is one of the pioneers and the most recognized leaders in French VR research and its practical application. A Professor at Arts et Metiers ParisTech (ENSAM), the renowned French School of Engineering, Simon Richir is also the head of the “Presence & Innovation” research team (LAMPA Lab, EA1427). His research and teaching activities concentrate on technological innovation, engineering design process, innovative projects, and innovative uses of new advanced technologies such as Virtual Reality or Augmented Reality. In addition to these activities, Professor Richir is also the co-founder and the current scientific chair of one of the world’s most prestigious international events in Virtual Reality – the annual Laval Virtual International Conference (ACM VRIC). Simon Richir also served as the essential collaborator in the development of augmented virtual reality environments in medical training and practical operations – an approach that ultimately gained the status of a “routine approach” in medical education. For 20 years, he has been developing new uses of virtual reality across a wide range of application areas.

Pallot, M, and Richir, S (2016), Laval Virtual Vision 2025: blurring the lines between digital and physical worlds, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 1–8, Los Angeles, California, USA, 20–22 Sept. 2016.

Invited Presentation: Mónica Cameirão

Recipient of the 2016 ISVR Early Career Investigator Award

Insights from 10 years of stroke virtual rehabilitation – a personal perspective

Mónica Cameirão

University of Madeira/Madeira Interactive Technologies Institute, PORTUGAL

BIO-SKETCH

Mónica is an Invited Assistant Professor and researcher at the University of Madeira (UMa) and the Madeira Interactive Technologies Institute (Madeira-ITI) in Portugal. Mónica holds a PhD in ICT from the Universitat Pompeu Fabra (Spain) and a MSc in Applied Physics from the Universidade de Aveiro (Portugal). She is currently the Portuguese coordinator of the Professional Masters on Human-Computer Interaction program that UMa/Madeira-ITI offers in conjunction with Carnegie Mellon University in Pittsburgh, USA. In the past she worked as research assistant at the SPECS Laboratory of the Universitat Pompeu Fabra and at the Institute of Neuroinformatics, ETH-Zürich, Switzerland; and was visiting scholar at the Quality of Life Technologies center of Carnegie Mellon University.

Since Mónica arrived in Madeira in 2011, she has been co-principal investigator and co-founder of the NeuroRehabLab Research Group, a research group created in the context of the Madeira-ITI with over 15 members, including PhD students, technicians, MSc students and other faculty members. The NeuroRehabLab is an interdisciplinary research group that investigates at the intersection of technology, neuroscience and clinical practice to find novel solutions to increase the quality of life of those with special needs.

In recent years, Mónica has been involved in the development and clinical assessment of virtual reality technologies for stroke rehabilitation and her work gave rise to a number of high impact publications in journals such as Stroke, Restorative Neurology and Neuroscience, and the Journal of Neuroengineering and Rehabilitation. Mónica’s work in VR explores specific brain mechanisms that relate to functional recovery to approach motor and cognitive stroke rehabilitation by means of non-invasive and low-cost technologies. Her research addresses aspects such as serious gaming, personalization of training, integrative motor-cognitive tasks, physiological computing or the emotional content of training stimuli. More recently, Mónica also started applying these principles to technology mediated fitness training for the elderly population.

Cameirão, M S (2016), Insights from 10 years of stroke virtual rehabilitation – a personal perspective, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 9–10, Los Angeles, California, USA, 20–22 Sept. 2016.

Impact of combined cognitive and motor rehabilitation in a virtual reality task: an on-going longitudinal study in the chronic phase of stroke

A L Faria, J Couras, M S Cameirão, T Paulino, G M Costa, S Bermúdez i Badia

Universidade de Coimbra/Madeira Interactive Technologies Institute, Funchal/Centro Médico da Murtosa, Aveiro/Universidade da Madeira, Funchal, PORTUGAL

ABSTRACT

Stroke is one of the most common causes of acquired disability, leaving numerous adults with cognitive and motor impairments, and affecting patients' capability to live independently. Virtual Reality (VR) based methods for stroke rehabilitation have mainly focused on motor rehabilitation but there is increasing interest towards the integration of cognitive training for providing more effective solutions. In this work we present a VR cognitive and motor training task – the Reh@Task – and the preliminary results from an ongoing one-month longitudinal intervention. We show the results from twelve patients divided in two groups: experimental and control. Both groups were enrolled in conventional occupational therapy, which mostly involves motor training. Additionally, the experimental group performed a specific attention and memory training with the Reh@Task and the control group performed time-matched conventional occupational therapy. This VR-based task consists of performing adapted arm reaching movements and has difficulty progression levels implemented with guidelines from a participatory design study. We assessed the impact of both interventions post-treatment (4-5 weeks) and at 4 weeks follow-up through the Montreal Cognitive Assessment, Single Letter Cancellation, Digit Cancellation, Bells Test, Fugl-Meyer, Chedoke Arm and Hand Activity Inventory, Modified Ashworth Scale and Barthel Index. A within groups analysis revealed significant improvements with respect to baseline in the global cognitive functioning in both groups, but only the patients who used the Reh@Task improved significantly in attention and memory. With respect to the motor domain, the control group showed greater improvements. Nevertheless, both groups improved significantly in the functional recovery of the hand and arm scores, revealing that both interventions had an impact in the use of the hand and arm in the activities of daily living. Overall, results are supportive of the viability of tools that combine motor and cognitive training, such as the Reh@Task.

Interaction with the Reh@Task through the AnTS tracking software.

Faria, AL, Couras, J, Cameirão, MS, Paulino, T, Costa, GM, and Bermúdez i Badia, S (2016), Impact of combined cognitive and motor rehabilitation in a virtual reality task: an on-going longitudinal study in the chronic phase of stroke, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 11–19, Los Angeles, California, USA, 20–22 Sept. 2016.

Session I: Stroke Rehabilitation

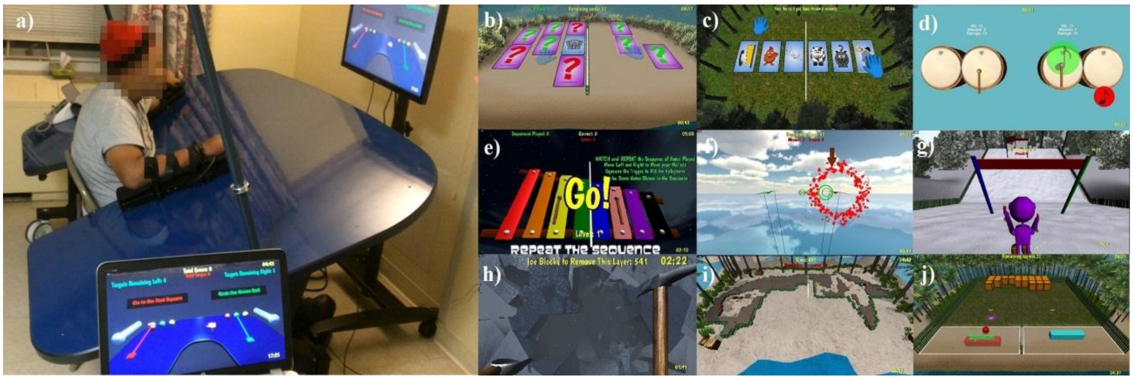
Longitudinal study of integrative virtual rehabilitation use in skilled nursing facility maintenance programs for residents with chronic stroke

G House, G Burdea, N Grampurohit, K Polistico, D Roll, F Damiani,
S Keeler, J Hundal, S Pollack

Bright Cloud International Corp, Highland Park, NJ/Roosevelt Care Center, Edison, NJ/JFK Hartwyck at Edison Estates, Edison, NJ/Hundal Neuropsychology Group, Watchung, NJ/Data Driven Innovation, Westhampton, NY, USA

ABSTRACT

The objective of this 45-week longitudinal controlled study was to examine the effects of integrative virtual rehabilitation with BrightArm Duo System for the maintenance of skilled nursing facility programs for elderly residents with chronic stroke. The experimental group trained intensely for 8 weeks followed by 3 booster periods at 8-week intervals. The sessions were supervised by an occupational therapist. The control (n=3) and experimental (n=7) groups both received standard-of-care maintenance. The improvement for the experimental group was significantly better than the controls in standardized assessments of UE range of motion (p=0.04), strength, and function (p=0.035), and for cognition and emotion (p=0.0006).



a) BrightArm system with subject training bimanually on Pick & Place game. Additional games: b) Card Island; c) Remember that Card ; d) Musical Drums; e) Xylophone; f) Kites; g) Arm Slalom; h) Avalanche; i) Treasure Hunt; and j) Breakout 3D.

House, G, Burdea, G, Grampurohit, N, Polistico, K, Roll, D, Damiani, F, Keeler, S, Hundal, J, and Pollack, S (2016), Longitudinal study of integrative virtual rehabilitation use in skilled nursing facility maintenance programs for residents with chronic stroke, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 21–29, Los Angeles, California, USA, 20–22 Sept. 2016.

Session I: Stroke Rehabilitation

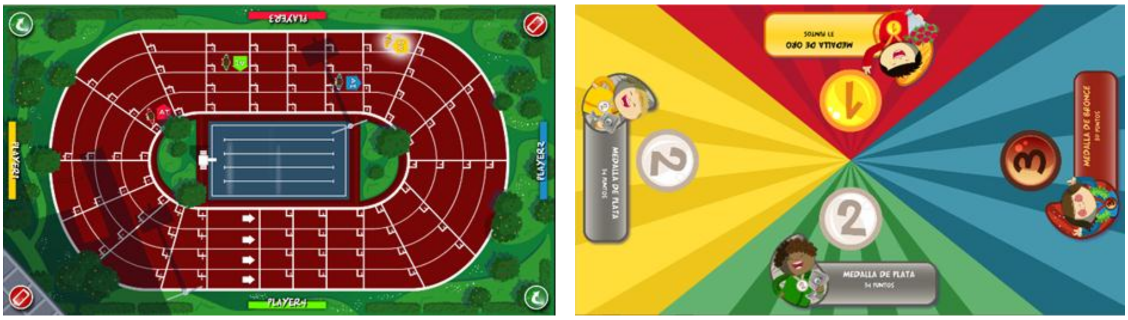
Competition improves attention and motivation after stroke

R Llorens, M D Navarro, E Noé, M Alcañiz

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

ABSTRACT

Cognitive deficits are a common sequelae after stroke. Among them, attention impairments have the highest incidence and limit functional recovery and quality of life. Different strategies to improve attention have been presented through the years, even though its effectiveness is still unclear. Basing on the human competitive nature, competitive strategies have been proposed to increase motivation and intensity. However, this approach has been never applied to train attention after stroke. In this paper, we present a randomized controlled trial that evidences the important role of competition in cognitive functioning. Our results support that competitive strategies combining virtual reality-based and paper and pencil tasks can improve attention and motivation after stroke to a greater extent than non-competitive paper and pencil tasks.



Snapshots of the main screen (left) and the results screen after each exercise (right).

Llorens, R, Navarro, MD, Noé, E, and Alcañiz, M (2016), Competition improves attention and motivation after stroke, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 31–39, Los Angeles, California, USA, 20–22 Sept. 2016.

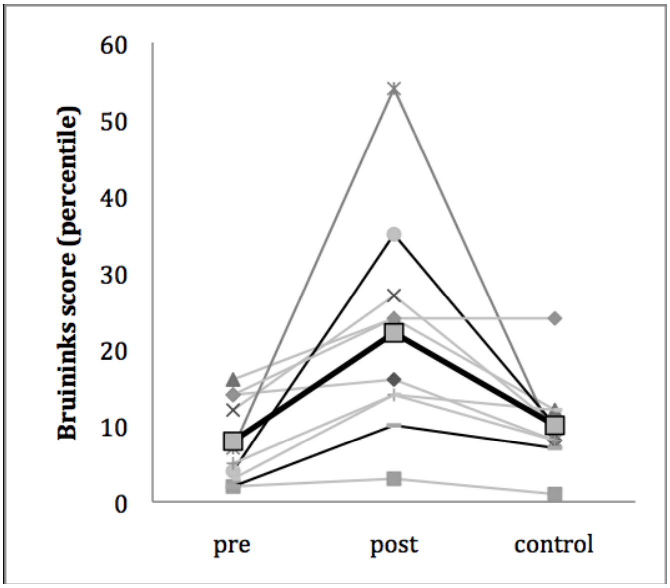
Current issues and challenges in research on virtual reality therapy for children with neurodisability

W J Farr, I Male, D Green, C Morris, H Gage, S Bailey, S Speller,
V Colville, M Jackson, S Bremner, A Memon

Sussex Community NHS Foundation Trust, Brighton/Oxford Brookes University/University of Exeter/Sussex Community NHS Foundation Trust, Brighton/University of Surrey/Brighton and Sussex Medical School, Brighton, ENGLAND

ABSTRACT

A PICO (population, intervention, comparison, outcome) approach is adopted to discuss issues and challenges in virtual reality therapy research in community health settings. Widespread variation within and between populations, e.g. co-morbid conditions, complicates treatment fidelity and applicability. Interventions require flexible dose and frequency to fit into children's family circumstances, with clearly employed specialist paediatric research staff. Comparisons require adaptation to digital technology, and keep pace with development. Outcomes may overstate the impact of virtual reality therapy and technological novelty, while not fully unpacking hidden digital effects. A wide set of agreed, flexible, and patient-centred outcome measures are required to establish positive clinical baseline.



Change in BOT-2 percentile for individual children using the Wii Fit as a treatment for DCD in a school setting; group A in a crossover study received intervention initially and then acted as controls. Mean result shown by thickened black line.

Farr, WJ, Male, I, Green, D, Morris, C, Gage, H, Bailey, S, Speller, S, Colville, V, Jackson, M, Bremner, S, and Memon, A (2016), Current issues and challenges in research on virtual reality therapy for children with neurodisability, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 41–48, Los Angeles, California, USA, 20–22 Sept. 2016.

Using virtual interactive training agents with adults with autism and other developmental disabilities

T Bresnahan, A A Rizzo, S L Burke, M Partin, R M Ahlness, M Trimmer

The Dan Marino Foundation, Fort Lauderdale/ University of Southern California – Institute for Creative Technologies, Los Angeles/Florida International University, Miami, USA

ABSTRACT

Conversational Virtual Human (VH) agents are increasingly being used to support role-play experiential learning across a range of use-cases and populations. This project examined whether use of the Virtual Interactive Training Agent (VITA) system would improve job interviewing skills in a sample of persons with autism or other developmental disability. The study examined performance differences between baseline and final interviews in face-to-face and virtual reality conditions, and whether statistically significant increases were demonstrated between interviewing conditions. Paired samples t-tests were utilized to examine mean changes in performance by interview stage and in the overall difference between baseline and final interview stages. The preliminary results indicated that VITA is a positive factor when preparing young adults with autism or other developmental disability for employment interviews. Statistically significant results were demonstrated across all pilot conditions and in all but one post-assessment condition.

User interacting with components of the VITA system.

Bresnahan, T, Rizzo, AA, Burke, SL, Partin, M, Ahlness, RM, and Trimmer, M (2016), Using virtual interactive training agents with adults with autism and other developmental disabilities, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 49–56, Los Angeles, California, USA, 20–22 Sept. 2016.

Session II: Neurodisability/Behaviour

Clinical interviewing by a virtual human agent with automatic behavior analysis

A A Rizzo, G Lucas, J Gratch, G Stratou, L-P Morency,
R Shilling, A Hartholt, S Scherer

Institute for Creative Technologies, University of Southern California, USA

ABSTRACT

SimSensei is a Virtual Human (VH) interviewing platform that uses off-the-shelf sensors (i.e., webcams, Microsoft Kinect and a microphone) to capture and interpret real-time audiovisual behavioral signals from users interacting with the VH system. The system was specifically designed for clinical interviewing and health care support by providing a face-to-face interaction between a user and a VH that can automatically react to the inferred state of the user through analysis of behavioral signals gleaned from the user's facial expressions, body gestures and vocal parameters. Akin to how non-verbal behavioral signals have an impact on human-to-human interaction and communication, SimSensei aims to capture and infer user state from signals generated from user non-verbal communication to improve engagement between a VH and a user and to quantify user state from the data captured across a 20 minute interview. As well, previous research with SimSensei indicates that users engaging with this automated system, have less fear of evaluation and self-disclose more personal information compared to when they believe the VH agent is actually an avatar being operated by a "wizard of oz" human-in-the-loop (Lucas et al., 2014). The current study presents results from a sample of military service members (SMs) who were interviewed within the SimSensei system before and after a deployment to Afghanistan. Results indicate that SMs reveal more PTSD symptoms to the SimSensei VH agent than they self-report on the Post Deployment Health Assessment. Pre/Post deployment facial expression analysis indicated more sad expressions and fewer happy expressions at post deployment.

User with SimSensei virtual clinical interviewer.

Rizzo, AA, Lucas, G, Gratch, J, Stratou, G, Morency, L-P, Shilling, R, Hartholt, A, and Scherer, S (2016), Clinical interviewing by a virtual human agent with automatic behavior analysis, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 57–63, Los Angeles, California, USA, 20–22 Sept. 2016.

Session III: Interaction

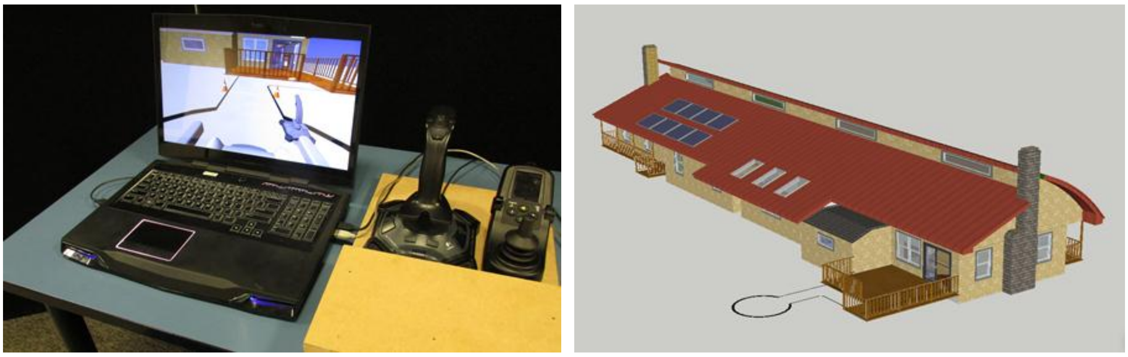
Impact of the visual representation of the input device on driving performance in a power wheelchair simulator

A Alshaer, D O'Hare, S Hoermann, H Regenbrecht

University of Otago, Dunedin, NEW ZEALAND/University of Sydney, AUSTRALIA

ABSTRACT

Virtual reality-based power wheelchair simulators can help potential users to be assessed and trained in a safe and controlled environment. Although now widely used and researched for several decades, many properties of virtual environments are still not yet fully understood. In this study, we evaluated the effects of the visual representation of the input device in a virtual power wheelchair simulator. We compared the virtual display of a standard gaming joystick with that of a proprietary power wheelchair joystick while users used either of the real world counterparts, and measured the effects on driving performance and experience. Four experimental conditions comprising two visual virtual input modalities and their two real counterparts as independent variables have been studied. The results of the study with 48 participants showed that the best performance was obtained for two of three performance indicators when a virtual representation of the PWC joystick was displayed, regardless of what type of joystick (real PWC or gaming joystick) was actually physically used. Despite not explicitly being made aware of by the experimenter, participants reported noticing the change in the visual representation of the joysticks during the experiment. This supports the theory that the effects of virtual reality representations have a significant impact on the user experience or performance, and visual properties need to be carefully selected. This is specifically important for applications where the transfer effects to real world scenarios is sought and ecological valid simulation is aimed for.



Experiment setup (left): Alienware laptop, gaming joystick, and PWC joystick; an outside view of the house environment used in our simulation (right).

Alshaer, A, O'Hare, D, Hoermann, S, and Regenbrecht, H (2016), Impact of the visual representation of the input device on driving performance in a power wheelchair simulator, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 65–72, Los Angeles, California, USA, 20–22 Sept. 2016.

Session III: Interaction

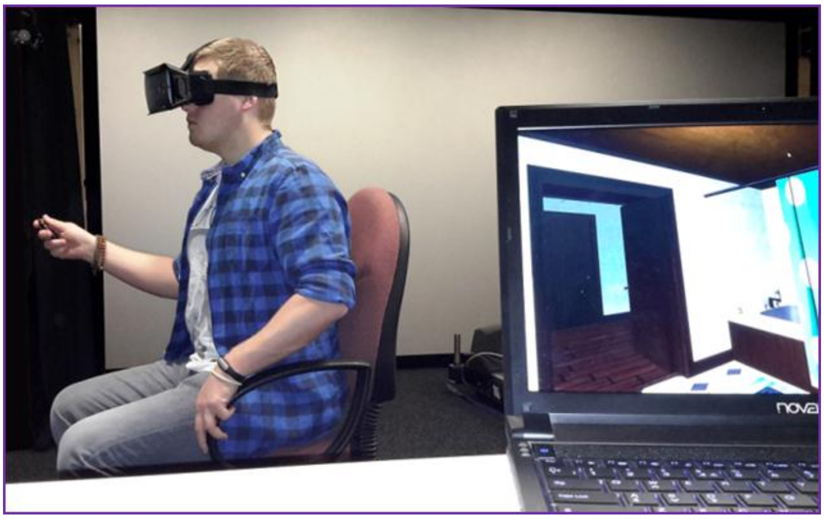
Influence of navigation interaction technique on perception and behaviour in mobile virtual reality

W Powell, V Powell, P Brown, M Cook, J Uddin

University of Portsmouth, UK

ABSTRACT

In recent years the development of affordable virtual reality has opened up enormous possibilities for virtual rehabilitation, and the introduction of ultra-low cost mobile VR such as Google Cardboard has real potential to put virtual rehabilitation right into patient's homes. However, the limited interaction possibilities when a mobile phone is mounted into a headset mean that these devices are generally used for little more than passive viewing. In this paper we present an evaluation of three approaches to supporting navigation in mobile VR, and discuss some of the potential hazards and limitations.



The six target locations visited in the study in sequence from left to right, before returning to the starting location (top); the experimental setup (below).

Powell, W, Powell, V, Brown, P, Cook, M, and Uddin, J (2016), Influence of navigation interaction technique on perception and behaviour in mobile virtual reality, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 73–81, Los Angeles, California, USA, 20–22 Sept. 2016.

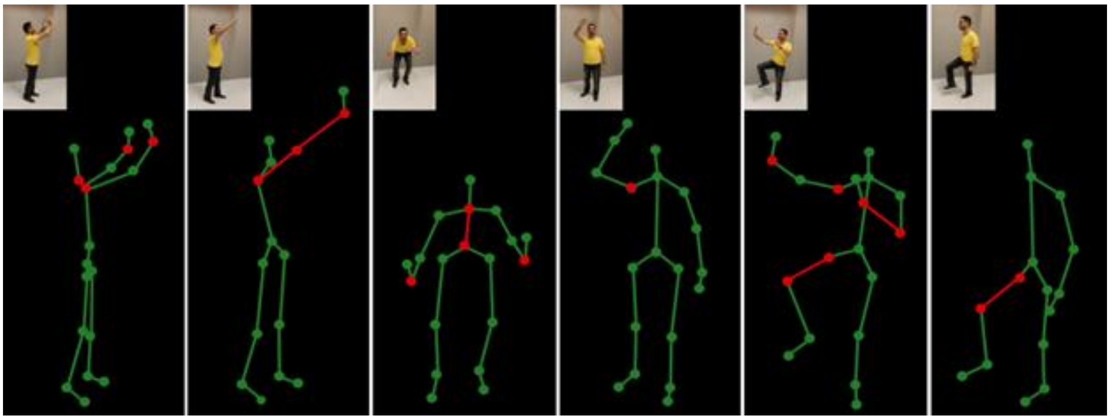
Study of stressful gestural interactions: an approach for assessing their negative physical impacts

S Ahmed, L Leroy, A Bouaniche

Université Paris, FRANCE

ABSTRACT

Despite the advantages of gestural interactions, they involve several drawbacks. One major drawback is their negative physical impacts. To reduce them, it is important to go through a process of assessing risk factors to determine the interactions' level of acceptability and comfort so as to make them more ergonomic and less tiring. We propose a method for assessing the risk factors of gestures based on the methods of posture assessment in the workplace and the instructions given by various standards. The goal is to improve interaction in virtual environments and make it less stressful and more effortless.



Stressed joints, colored red in the application real-time output (simulated).

Ahmed, S, Leroy, L, and Bouaniche, A (2016), Study of stressful gestural interactions: an approach for assessing their negative physical impacts, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 83–91, Los Angeles, California, USA, 20–22 Sept. 2016.

Open rehabilitation initiative: design and formative evaluation

S Bermúdez i Badia, J E Deustch, R Llorens

Universidade da Madeira, Funchal, PORTUGAL/ Rutgers University, Newark, NJ, USA/Universitat Politècnica de València/Fundación Hospitales NISA, Valencia, SPAIN

ABSTRACT

Development and testing of virtual environments for rehabilitation is a lengthy process which involves conceptualization, design, validation, proof concept testing and ultimately, if appropriate, randomized controlled trials. Ironically, once vetted, many of these VEs are not available to clinicians or their patients. To address the challenge of transferring research grade technology from the lab to the clinic the authors have created the Open Rehabilitation Initiative. It is an international independent online portal that aims to help clinicians, scientists, engineers, game developers and end-users to interact with and share virtual rehabilitation tools. In this paper, the conceptualization, development and formative evaluation testing are described. Three groups of developers of VEs (n=3), roboticists who use VEs for robot interactivity (n=10) and physical therapists (n=6) who are the clinicians end-users participated in the study. Interviews, focus groups and administration of the System Usability Scale (SUS) were used to assess acceptability. Data were collected on three aspects: 1) discussion of what a resource might look like; 2) interaction with the site; and 3) reaction to the proposed site and completion of the SUS. Interviews and focus groups were recorded and transcribed. Data from the SUS was analyzed using a One-way ANOVA. There was no significant difference by groups. However, the clinicians' mean score of 68 on the SUS was just at the acceptable level, while the developers and roboticists scored above 80. While all users agreed that the site was a tool that could promote collaboration and interaction between developers and users, each had different requirements for the design and use. Iterative development and discussion of scaling and sustaining the site is ongoing.

The Open Rehab Initiative content is organized according to the following taxonomy: Upper Limb, Balance, Mobility, Cognition and Fitness.

Bermúdez i Badia, S, Deustch, JE, and Llorens, R (2016), Open rehabilitation initiative: design and formative evaluation, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 93–100, Los Angeles, California, USA, 20–22 Sept. 2016.

Remote communication, examination and training in stroke, Parkinson´s and COPD care: work in progress testing 3D camera and movement recognition technologies together with new patient centered ICT services

M Rydmark, J Broeren, J Jalminger, L-Å Johansson, M Johanson, A Ridderstolpe

The Sahlgrenska Academy, University of Gothenburg/
Alkit Communications, Mölndal, SWEDEN

ABSTRACT

This paper describes strategy and work in progress. The combination of patient centered care where many care and nursing units are collaborating with focus on, and in concordance with the patient, the ability to project information focused on the patient total situation and needs independent from where the information was created, the ability to use sensor technology to collect a wide range of aspects of the individuals health situation, the ability to use sensor technology to assess movements both for assessment and intervention purposes, to keep the care and nursing process together through module based information services and a structured care plan containing goals, sub goals, defined activity types and a wide range of health status data involving great opportunities for patients having chronic diseases. This group of patients causes extensive resource consumption for society. Well-structured data and semantic definition of data is a key for communication between different types of multi-professionals actors with different background. New technology, such as a wide range of sensor types, allows the possibly to capture large amounts of data both for assessment and intervention purposes in a continuous way over time. One example is how each planned patient activity has been performed and resulting health status aspects. This research group has worked on these issues for several years and some important milestones have been reached. From a chronic point of view three groups of patients are the focus: stroke patients, chronic obstructive pulmonary disease (COPD) patients and patients with Parkinson's disease. Collaboration approaches, communication technology and adapted information services allow new ways to perform home based care. Integrated monitoring services of planned activities like motion activities using 3D sensors allows professionals and patient to, in an exact way, follow planned and executed motion activities which are of great importance to many patient needs.

Rydmark, M, Broeren, J, Jalminger, J, Johansson, L-Å, Johanson, M, and Ridderstolpe, A (2016), Remote communication, examination and training in stroke, Parkinson´s and COPD care: work in progress testing 3D camera and movement recognition technologies together with new patient centered ICT services, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 101–106, Los Angeles, California, USA, 20–22 Sept. 2016.

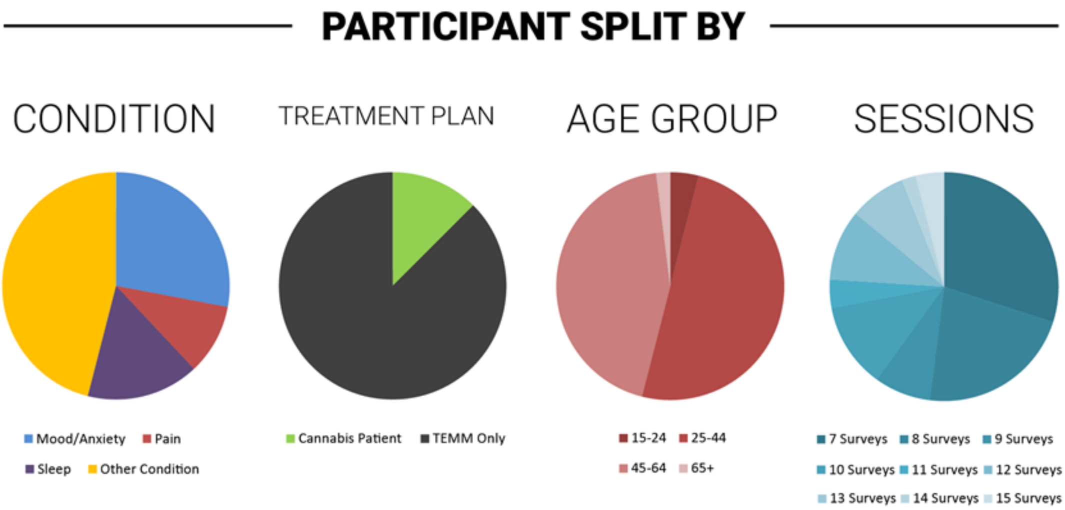
Authenticating the subjective: a naturalistic case study of a high-usability electronic health record for virtual reality therapeutics

H J Moller, L Saynor

University of Toronto/OCAD University, Toronto/PRAXIS Holistic Health, Toronto, CANADA

ABSTRACT

Using data from our established Technology-Enhanced Multimodal Meditation (TEMM) stress-reduction program employing the electronic health record system Wellpad, we illustrate the value of developing a qualitative data-analysis approach to inform clinical practice in the rapidly emerging field of immersive therapeutics. In examining "rich data" of a naturalistic 50-patient TEMM cohort, indicates that, as with design of VR therapeutics, there is a highly salient role for immersive diagnostics, which ultimately relates to consumer satisfaction, both for patient and health-care practitioner.



Various proportional classifications of the 50-patient sample.

Moller, HJ, and Saynor, L (2016), Authenticating the subjective: a naturalistic case study of a high-usability electronic health record for virtual reality therapeutics, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 107–112, Los Angeles, California, USA, 20–22 Sept. 2016.

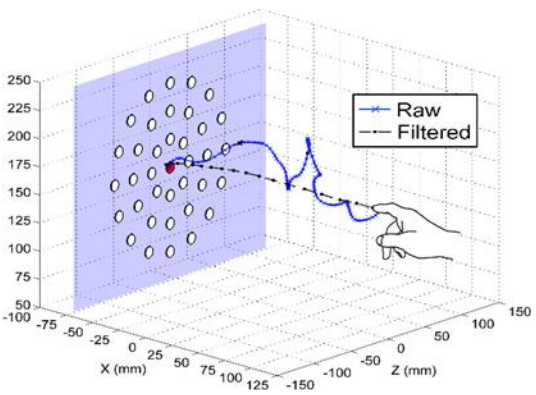
Applying Bayesian modelling for inclusive design under health and situational induced impairments

B I Ahmad, P M Langdon, S J Godsill

University of Cambridge, UK

ABSTRACT

Predictive pointing enables realising smart interfaces, which are capable of inferring the user intent, early in the pointing task, and accordingly assisting the on-display target acquisition (pointing and selection). It adopts a Bayesian framework to effectively model the user pointing behaviour and incorporate the present perturbations induced by situational impairments as well as inaccuracies in the utilised sensing technology. The objective of the predictive pointing system is to minimise the cognitive, visual and physical effort associated with acquiring an interface component when the user input is perturbed due to a situational impairment, for example, to aid drivers select icons on a display in a moving car via free hand pointing gestures. In this paper, we discuss the ability of the predictive pointing or display solution to simplify and expedite human computer interaction when the user input is perturbed due to health induced impairments and disability, rather than a situational impairment. Examples include users with tremors, spasms, or other motor impairments. Given the flexibilities acceded by the Bayesian formulation, the applicability of the predictive pointing to inclusive design in general is addressed. Its intent prediction functionality can be adapted to the user's physical capabilities and pointing characteristics or style, thereby catering for wide ranges of health induced impairments, such as those arising from ageing. It is concluded that predictive displays can significantly facilitate and reduce the effort required to accomplish selection tasks on an interactive display when the user input is perturbed due to health or physical impairments, especially when pointing in 3D with free hand pointing gestures.



3D pointing track before (blue) and after (dashed) applying a variable rate particle filter.

Ahmad, BI, Langdon, PM, and Godsill, SJ (2016), Applying Bayesian modelling for inclusive design under health and situational induced impairments, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 113–121, Los Angeles, California, USA, 20–22 Sept. 2016.

Session V: Visual Impairments

Tele-guidance based orientation and mobility system for visually impaired and blind persons

B Chaudary, P Pulli, I Paajala, E Keino

University of Oulu, FINLAND

ABSTRACT

The design and development of tele-assistance services have received great consideration in the domain of healthcare lately. Telecare solutions are seen as a potential means of addressing the future care needs of ageing societies. With the growing proportion of dependent people (ageing, disabled users), tele-assistance and tele-monitoring platforms will play a significant role to provide efficient and less-costly remote care and support. It will allow aged and disabled persons to maintain their independence and lessen the burden and cost of caregiving. In the case of visually impaired persons (VIP) and blind persons, guide dogs and white canes provide them a fair degree of independence. However, those are very limited in guiding the user towards a specific desired location, especially in an unknown environment. The assistance of other people presents a feasible solution, though it does not improve the idea of autonomous guidance and privacy. The concept of proposed tele-guidance system is based on the idea that a blind pedestrian can be assisted by spoken instructions from a remote caregiver who receives a live video stream from a camera carried by her. The assistive tools have reportedly acceptance issues by VIP. The paper also presents a qualitative study using a modified version of UTAUT-2 (Unified Theory of Acceptance and Use of Technology) to find out causes for acceptance issues in navigation tools for visually impaired. Another goal of the study was to validate the UTAUT2-model as suitable for researching acceptance issues of navigation assistance tools of VIP.

Tele-guidance system concept.

Chaudary, B, Pulli, P, Paajala, I, and Keino, E (2016), Tele-guidance based orientation and mobility system for visually impaired and blind persons, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 123–132, Los Angeles, California, USA, 20–22 Sept. 2016.

Session V: Visual Impairments

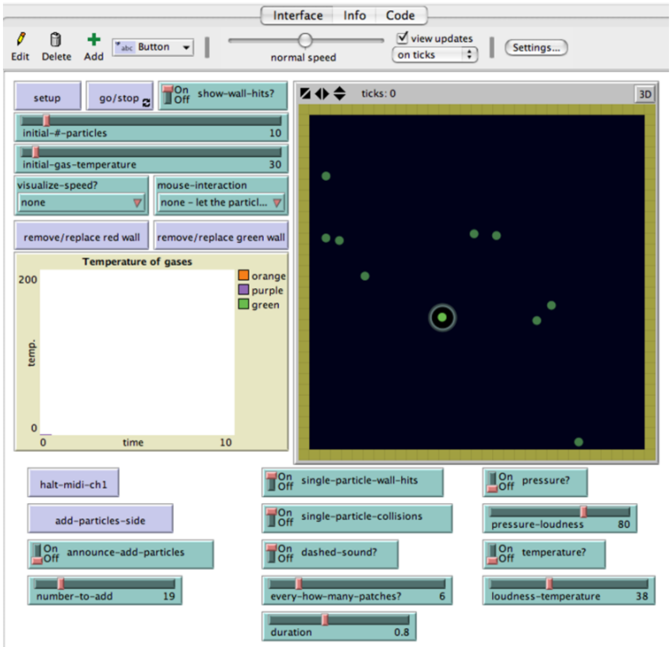
Computer model based audio and its influence on blind students' learning about gas particle behavior

N Hagab, O Lahav, V Talis

Tel Aviv University, ISRAEL

ABSTRACT

This paper focuses on the need of students who are blind to access science curriculum learning materials. Net Logo is a widely used computational agent-based modelling language that enables exploring and constructing models of complex systems. The Listen-to-Complexity environment is based on Net Logo and involves sonified feedback that was adapted to users who are blind. This study examines the scientific conceptual knowledge, systems reasoning, and Kinetic Molecular Theory of gas in chemistry that were learned as a result of interaction with the Listen-to-Complexity environment by people who are blind as shown in their answers to a pre- and post-test. Five participants who are blind volunteered to participate in this research. The preliminary findings are encouraging with regard to the sonified model's efficacy in providing access to central and difficult scientific concepts, even when the target phenomenon is complex. The benefits of this longitudinal research are likely to have an impact on science education for students who are blind, supporting their inclusion in the K-12 academic curriculum on an equal basis with sighted users.



L2C sonified model of gas particles in a container.

Hagab, N, Lahav, O, and Talis, V (2016), Computer model based audio and its influence on blind students' learning about gas particle behavior, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 133–138, Los Angeles, California, USA, 20–22 Sept. 2016.

Session V: Visual Impairments

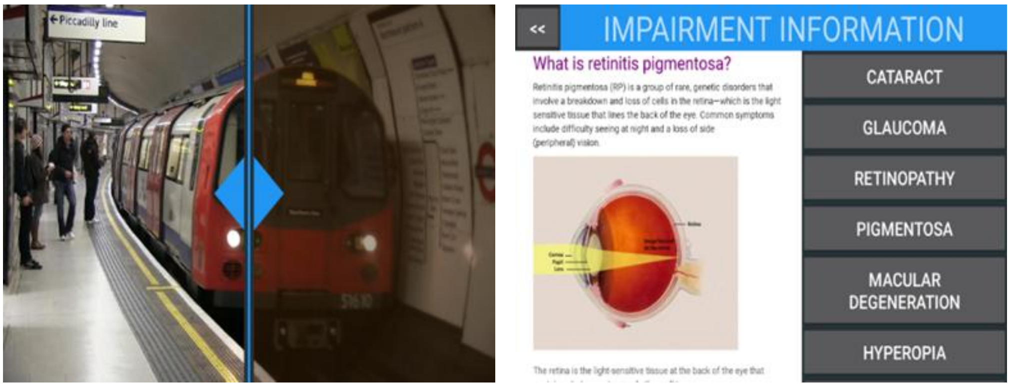
Visual impairment simulator for auditing and design

G Stewart, R J McCrindle

University of Reading, UK

ABSTRACT

Individuals within the visually impaired community often have difficulty navigating environments due to the different ways in which they view the world, with even apparently simplistic locations frequently being challenging to traverse. It is therefore important when designing architecture or environments, to take into account the perspectives of people with visual impairments in order to ensure that design outcomes are inclusive and accessible for all. Although there is documentation regarding guidance and procedures for design of inclusive spaces; architects, designers, and accessibility auditors often find it hard to empathize with visually impaired people. This project aims to make the process of inclusive design easier through the development of a mobile app, VISAD (Visual Impairment Simulator for Auditing and Design), which enables users to capture images or import CAD designs and apply image distortion techniques in order to replicate different visual impairments.



Comparison tool (left); information tool (right).

Stewart, G, and McCrindle, RJ (2016), Visual impairment simulator for auditing and design, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 139–148, Los Angeles, California, USA, 20–22 Sept. 2016.

Differential effect of neutral and fear-stimulus virtual reality exposure on physiological indicators of anxiety in acrophobia

P Maron, V Powell, W Powell

University of Portsmouth, UK

ABSTRACT

This paper presents a study which explores the physiological and behavioural indicators of anxiety during exposure to a virtual reality environment. Using 10 participants (5 with acrophobia and 5 control) the study aimed to determine whether an increase in heart rate (HR) from baseline to VR exposure is a sufficient measure for effectiveness of a virtual reality exposure therapy (VRET) stimulus, or whether there is a mediating effect of neutral VR exposure which should be taken into account. The participants all explored an immersive cityscape at ground level and at height, and both subjective and objective measures of physiological arousal were recorded. It was found that the VRET was successful in inducing an anxiety response in the participants with acrophobia, and moreover demonstrated that an increase in HR from baseline to VRET on its own should not be considered a reliable indicator of VRET efficacy, but that there should be an adjustment for the effect of neutral VR exposure on physiological arousal.

The motion capture suit with optical markers.

Maron, P, Powell, V, and Powell, W (2016), Differential effect of neutral and fear-stimulus virtual reality exposure on physiological indicators of anxiety in acrophobia, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 149–155, Los Angeles, California, USA, 20–22 Sept. 2016.

Session VI: Psychology/Communication

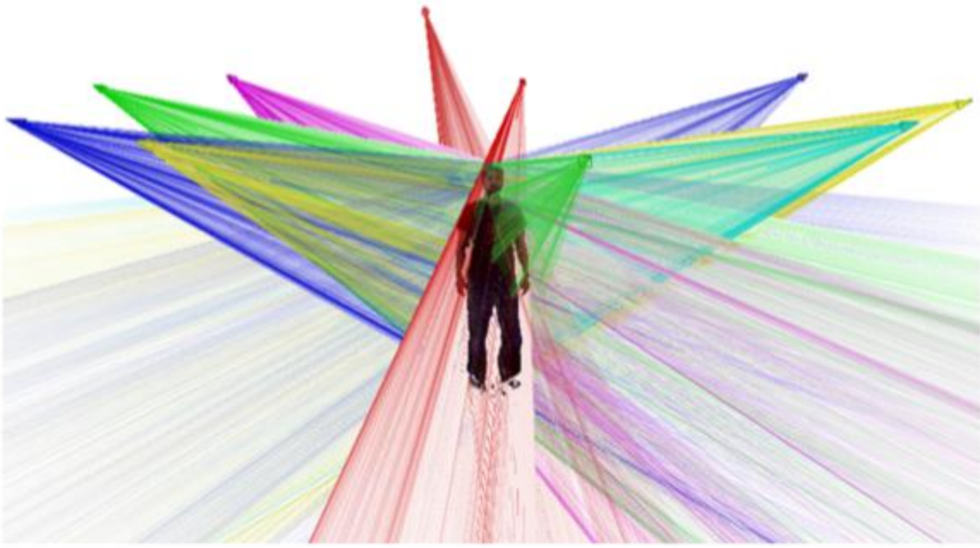
Bringing the client and therapist together in virtual reality telepresence exposure therapy

D J Roberts, A J Fairchild, S Campion, A S Garcia, R Wolff

University of Salford, Salford, UK

ABSTRACT

We present a technology demonstrator of the potential utility of our telepresence approach to supporting tele-therapy, in which client and remote therapist are immersed together. The aim is to demonstrate an approach in which a wide range of non-verbal communication between client and therapist can be contextualised within a shared simulation, even when the therapist is in the clinic and the client at home. The ultimate goal of the approach is to help the therapist to encourage the client to face a simulated threat while keeping them grounded in the safety of the present. The approach is to allow them to use non-verbal communication grounded in both the experience of the exposure and the current surroundings. While this is not new to exposure therapy, the challenges are: 1) to do this not only when the threat is simulated; and 2) when the client and therapist are apart. The technology approach combines immersive collaborative visualisation with free viewpoint 3D video based telepresence. The potential impact is to reduce dropout rate of exposure therapy for resistant clients.



3D reconstruction of a human in our telepresence system, showing lines from each camera derived from silhouettes.

Roberts, DJ, Fairchild, AJ, Campion, S, Garcia, AS, and Wolff, R (2016), Bringing the client and therapist together in virtual reality telepresence exposure therapy, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 157–163, Los Angeles, California, USA, 20–22 Sept. 2016.

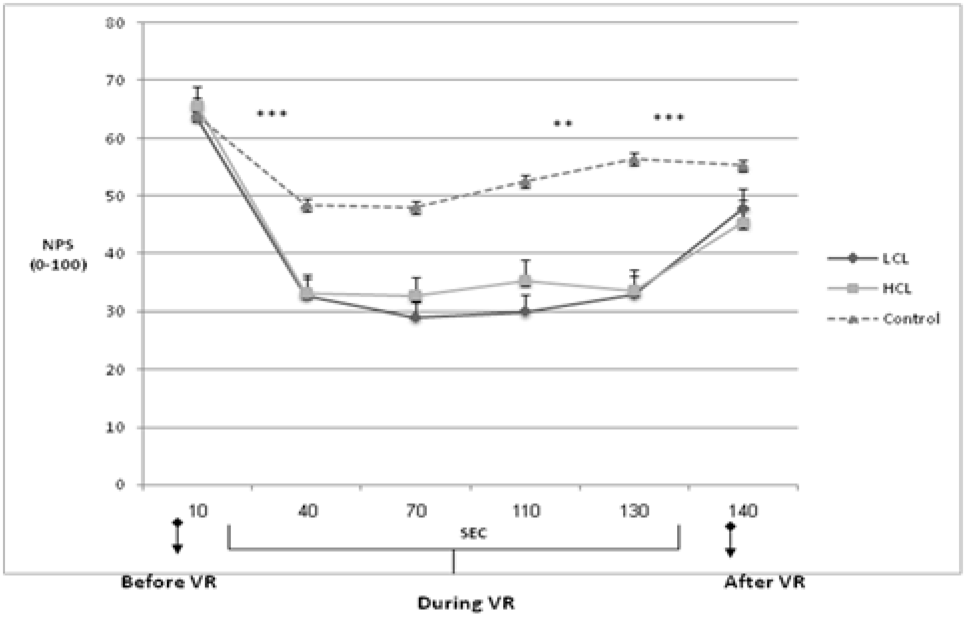
Experimental pain reduction in two different virtual reality environments: a crossover study in healthy subjects

N Demeter, D Pud, N Josman

University of Haifa, ISRAEL

ABSTRACT

The literature on unique virtual reality (VR) attributes impacting pain reduction is scarce. This study investigated the effect of two VR environments, with differing cognitive load (CL) demands, on experimental pain levels. Sixty-two students underwent psychophysical thermal pain tests, followed by exposure to tonic heat stimulation under one of three conditions: low CLVR (LCL), high CLVR (HCL), and a control. Significantly greater pain reduction occurred during VR compared to the control condition. Cognitive components predicted pain reduction during HCL only. Cognitive load involved in VR may influence the extent of pain decrease, a finding that may improve treatment protocols and promote future research.



Heat pain intensity during three study conditions (mean±SEM). Asterisks represent differences between the two VR conditions and control within two adjacent time points. LCL=low cognitive load VR, HCL=high cognitive load VR.

Demeter, N, Pud, D, and Josman, N (2016), Experimental pain reduction in two different virtual reality environments: A crossover study in healthy subjects, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 165–172, Los Angeles, California, USA, 20–22 Sept. 2016.

Integrative virtual reality therapy produces lasting benefits for a young woman suffering from chronic pain and depression post cancer surgery: a case study

G House, G Burdea, N Grampurohit, K Polistico, D Roll,
F Damiani, J Hundal, D Demesmin

Bright Cloud International Corp, Highland Park, NJ/Roosevelt Care Center, Edison, NJ/Hundal Neuropsychology Group, Watchung, NJ/University Pain Medicine Center, Summerset, NJ, USA

ABSTRACT

This case study was part of an evaluation of the BrightArm Duo Rehabilitation System for treating the effects of chronic upper body pain following breast cancer surgery. The subject was a 22-year old woman with burning and stabbing pain in the right upper arm. Training consisted of playing custom bimanual 3D games while seated at the gravity-modulating robotic table for 16 sessions over 8 weeks. Standardized assessments demonstrated a meaningful improvement in motor, cognitive and emotive domains with a statistically significant reduction in pain. Gains transferred to daily activities enabling the subject to resume full time employment, driving and socializing.

BrightArm Duo Table tilted upwards with two arm supports for user interaction and therapist laptop rendering Pick & Place game to the 27″ monitor.

House, G, Burdea, G, Grampurohit, N, Polistico, K, Roll, D, Damiani, F, Hundal, J, and Demesmin, D (2016), Integrative virtual reality therapy produces lasting benefits for a young woman suffering from chronic pain and depression post cancer surgery: a case study, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 173–182, Los Angeles, California, USA, 20–22 Sept. 2016.

Session VI: Psychology/Communication

Does mixed reality influence texting while walking among younger and older adults?

T Krasovsky, P L Weiss, R Kizony

University of Haifa/Sheba Medical Center, Tel Hashomer, ISRAEL

ABSTRACT

Young and older adults have difficulties in performance of an additional task while walking (dual task). This feasibility study investigates the dual task costs of texting on a mobile phone and walking among young and older adults, as well as the potential of a mixed reality app, which projects the real world onto the background of the mobile display, to modify these costs. Seven young (age 26.4±4.5 years) and 7 older (age 69.9±3.9 years) adults were asked to walk while texting on a custom-written mobile android app (with and without mixed reality display), as well as to perform each task (walking, texting) separately. Preliminary results show that dual task interference of both tasks is similar in both groups. Using a mixed reality display does not modify these costs, but does affect the subjective experience of the groups differently. This may be due to different levels of familiarity with mobile phone use in the two groups. Additional data is currently being collected.

An example of an off-the-shelf application (Type n walk, www.type-n-walk.com) projecting the real world view captured by the smartphone camera behind a data layer (e.g., used for writing text).

Krasovsky, T, Weiss, PL, and Kizony, R (2016), Does mixed reality influence texting while walking among younger and older adults?, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 183–191, Los Angeles, California, USA, 20–22 Sept. 2016.

Session VI: Psychology/Communication

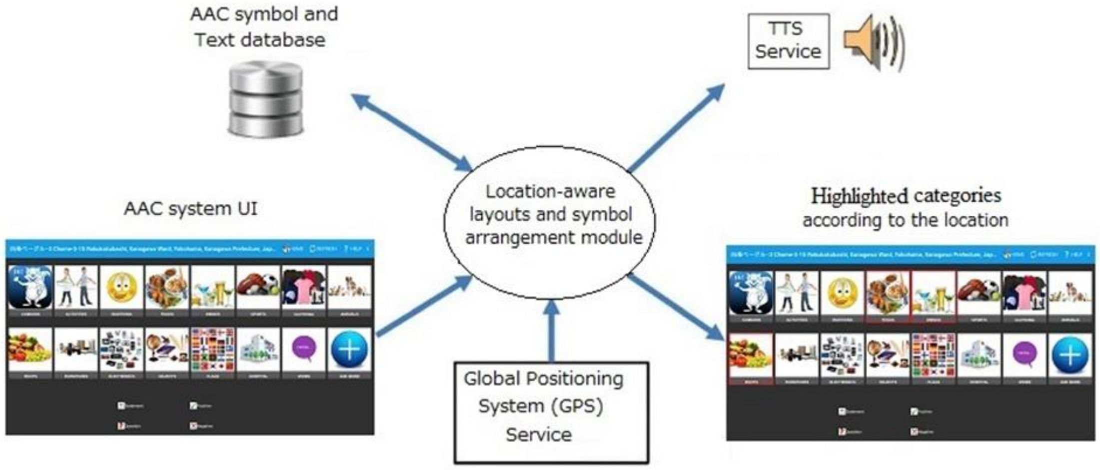
Designing a location-aware augmented and alternative communication system to support people with language and speech disorders

M S Hossain, M Takanokura, K Nakashima

Kanagawa University, Yokohama, JAPAN

ABSTRACT

Working with those who have speech and language disorders can be a great challenge for researchers. Language difficulties can significantly affect a user’s ability to communicate with others. Our aim is to design an Augmentative and Alternative Communication (AAC) system based on current location for people with language disorders in order to support communication in their everyday life. In this paper, we design a location based AAC system that provides a list of images that is able to assist in communication.



Architecture of the proposed location-aware AAC system.

Hossain, MS, Takanokura, M, and Nakashima, K (2016), Designing a location-aware augmented and alternative communication system to support people with language and speech disorders, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 193–199, Los Angeles, California, USA, 20–22 Sept. 2016.

Session VII: System Design/Self-management

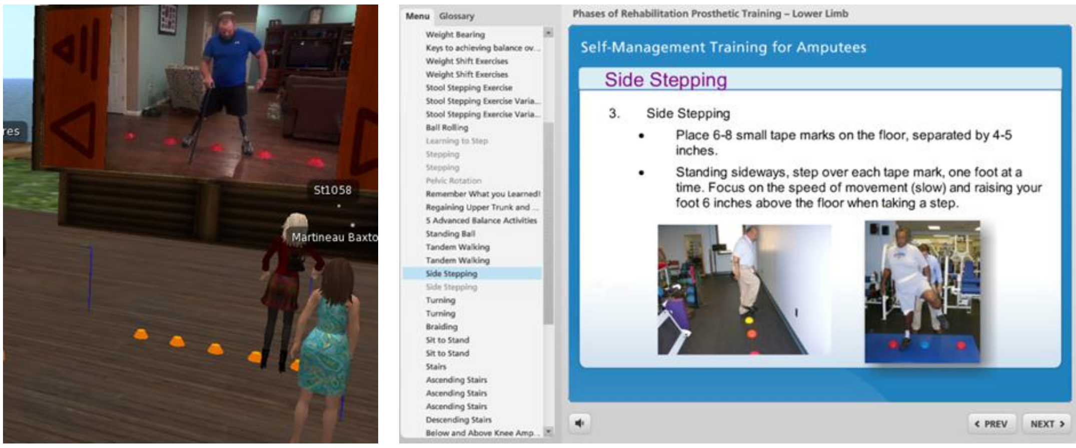
Comparison of functional benefits of self-management training for amputees under virtual world and e-learning conditions

S L Winkler, J A Kairalla, R Cooper, I Gaunaurd, M Schlesinger, A Krueger, A Ludwig

James A Haley VA Hospital, Tampa, FL/University of Florida, Gainesville/
Nova Southeastern University, Fort Lauderdale, FL/Miami VA Medical Center, FL/
Virtual Ability, Inc., Aurora, CO, USA

ABSTRACT

Amputation is a life-long condition. Throughout their lifespan, amputees will need health, wellness and prosthetic-related information. This project used a randomized design to compare two methods of disseminating an evidence-based self-management intervention: avatar-based virtual world and e-learning environments. Of the 57 subjects randomized, 37 (65%) completed the study. The virtual world group had a significantly higher drop-out rate than the e-learning group. Both groups marginally improved on self-efficacy, perceived social support, pain interference, and functional status outcomes with no significant results found between the groups.



A side-stepping balance exercise in the virtual world condition (left) and the e-learning condition (right).

Winkler, SL, Kairalla, JA, Cooper, R, Gaunaurd, I, Schlesinger, M, Krueger, A, and Ludwig, A (2016), Comparison of functional benefits of self-management training for amputees under virtual world and e-learning conditions, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 201–208, Los Angeles, California, USA, 20–22 Sept. 2016.

Choosing virtual and augmented reality hardware for virtual rehabilitation: process and considerations

S T Koenig, B S Lange

Katana Simulations Pty Ltd, Henley Beach South/Flinders University, Adelaide, AUSTRALIA

ABSTRACT

Virtual and Augmented Reality hardware has become much more affordable in the past three years, largely due to the availability of affordable sensors and smartphone displays as well as financial investments and buy-in through the entertainment industry. Many new consumer devices are becoming available to researchers, clinicians and software developers. With so many options available, planning a Virtual Rehabilitation project and selecting appropriate hardware components can be a challenge. This paper presents a stepwise selection process for Virtual and Augmented Reality hardware. The process is described through an example project and clinical and technical implications of each hardware choice are discussed.

Virtual Classroom scenario.

Koenig, ST, and Lange, BS (2016), Choosing virtual and augmented reality hardware for virtual rehabilitation: process and considerations, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 209–215, Los Angeles, California, USA, 20–22 Sept. 2016.

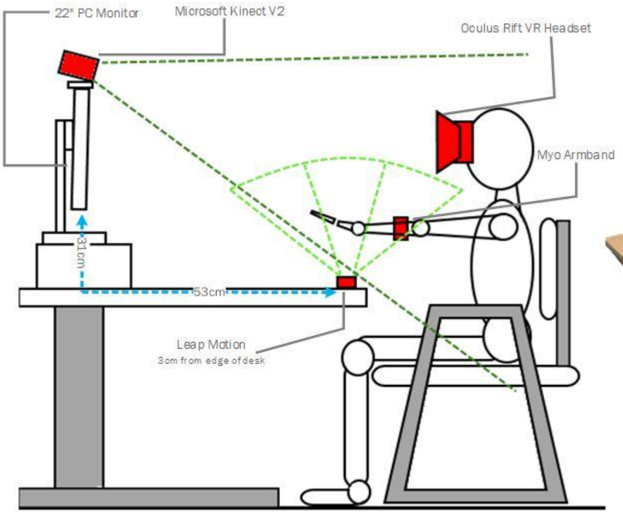
Usability and performance of Leap Motion and Oculus Rift for upper arm virtual reality stroke rehabilitation

D E Holmes, D K Charles, P J Morrow, S McClean, S M McDonough

Ulster University, Coleraine/Jordanstown, UK

ABSTRACT

Intensified rehabilitation is important for stroke survivors but difficult to achieve due to limited access to physiotherapy. We present a virtual reality rehabilitation system, Target Acquiring Exercise (TAGER), designed to supplement center-based physiotherapy by providing engaging and personalized exercises. TAGER uses natural user interface devices, the Microsoft Kinect, Leap Motion and Myo armband, to track upper arm and body motion. Linear regression was applied to 3D user motion data using four popular forms of Fitts's law and each approach evaluated. While all four forms of Fitt's Law produced similar results and could model users effectively, it may be argued that a 3D tailored form provided the best fit. However, we propose that Fitts's Law may be more suitable as the basis of a more complex model to profile user performance. Evaluated by healthy users TAGER proved effective, with important lessons learned which will inform future design.



Experimental setup.

Holmes, DE, Charles, DK, Morrow, PJ, McClean, S, and McDonough, SM (2016), Usability and performance of Leap Motion and Oculus Rift for upper arm virtual reality stroke rehabilitation, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 217–226, Los Angeles, California, USA, 20–22 Sept. 2016.

Expanded sense of possibilities: qualitative findings from a virtual self-management training for amputees

R Cooper, S L Winkler, M Schlesinger, A Krueger, A Ludwig

Nova Southeastern University, Fort Lauderdale, FL/James A Haley VA Hospital, Tampa, FL/Virtual Ability, Inc., Aurora, CO, USA

ABSTRACT

This paper presents the procedures and results of a qualitative study that was part of a larger study comparing two methods of accessing a self-management training for amputees: e-learning and a virtual world. Interviews were conducted in Second Life with ten subjects who completed the training in the virtual world and seven subjects who completed e-learning training. Interpretative Phenomenological Analysis (IPA) was used for qualitative data analysis, leading to the identification of 14 themes within five major categories. An overarching theme of the Second Life experience resulting from analysis was that of an expanded sense of possibilities.

		SL n=13	e-learning n=4
Age		52	62
Race/ethnicity	White	13	3
	Black	0	1
Gender	Male	10	2
	Female	3	2
Amputation	Unilateral UL	2	0
	Unilateral LL	10	3
	Bilateral LL	1	1
	Unilateral UL & Bilateral LL	0	0
Years since first amputation	0-5	9	3
	6-10	1	1
	11-15	1	1
	16-20	1	0
	>25	1	0
Etiology	Trauma	4	0
	Dysvascular	3	0
	Disease	6	4
Prosthetic use	Daily	9	3
	Weekly	0	1
	Did not use prosthesis	4	0

Cooper, R, Winkler, SL, Schlesinger, M, Krueger, A, and Ludwig, A (2016), Expanded sense of possibilities: qualitative findings from a virtual self-management training for amputees, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 227–232, Los Angeles, California, USA, 20–22 Sept. 2016.

Session VIII: Stroke/General Rehabilitation

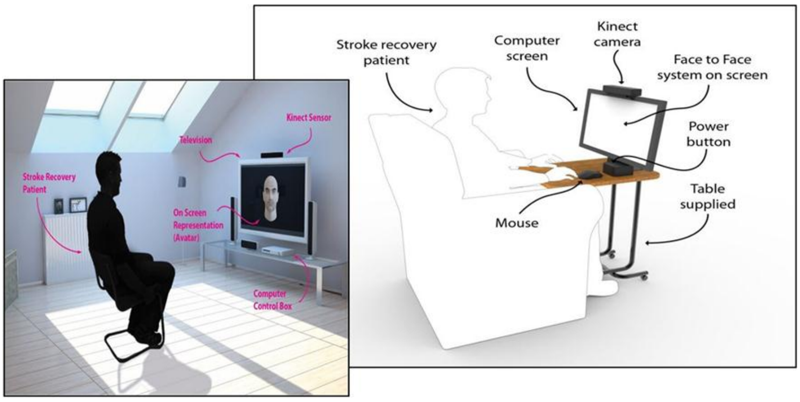
Face to face: an interactive facial exercise system for stroke patients with facial weakness

P Breedon, P Logan, D Pearce, J Edmans, B Childs, R O'Brien

Nottingham Trent University/University of Nottingham/Barker Brettell LLP, Birmingham/Maddison Product Design Ltd, Fittleworth, UK

ABSTRACT

Each year 152,000 people in the UK have a stroke. Almost all have an initial facial weakness. Many resolve in the first few days but it is estimated that 26,000 people experience some kind of long-term paralysis in their face. This may impact on their eating, drinking, speaking, facial expression, saliva management, self-image and confidence. A survey of 107 UK based clinicians found that routine treatment of facial weakness was provision of exercises with a written instruction sheet. The UK National Stroke Clinical Guidelines recommend that patients undertake 45 minutes of therapy per day, but anecdotal evidence suggests that patients have poor adherence to the exercises because they find them boring and there is no feedback to help them see a difference. A multidisciplinary team, which includes patients, researchers and therapists have produced a working prototype system to improve facial weakness. It is called Face to Face and includes a Kinect sensor, a small form PC and a monitor. Patients follow exercises given by a therapist on the screen; the system records and simultaneously gives feedback, with a facial recognition algorithm providing tracking data for each captured frame of the user's face. Results from our small clinical trial indicate that the system is more successful at getting patients to complete their exercises than using a mirror, patients liked it, and they said it had helped improve their facial symmetry. Therapists said Face to Face encouraged patients to exercise daily, they liked the fact that it could be individually programmed and could record how much the patient had exercised. Based on the initial project work and positive outcomes Face to Face aims to help patients practice their facial muscle exercises to speed their recovery, providing direct benefits in terms of costs and time, and offering patients significant improvements.



Initial concept (inset) and PPI informed system design.

Breedon, P, Logan, P, Pearce, D, Edmans, J, Childs, B, and O'Brien, R (2016), Face to face: an interactive facial exercise system for stroke patients with facial weakness, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 233–240, Los Angeles, California, USA, 20–22 Sept. 2016.

Evaluating automated real time feedback and instructions during computerized mirror therapy for upper limb rehabilitation using augmented reflection technology

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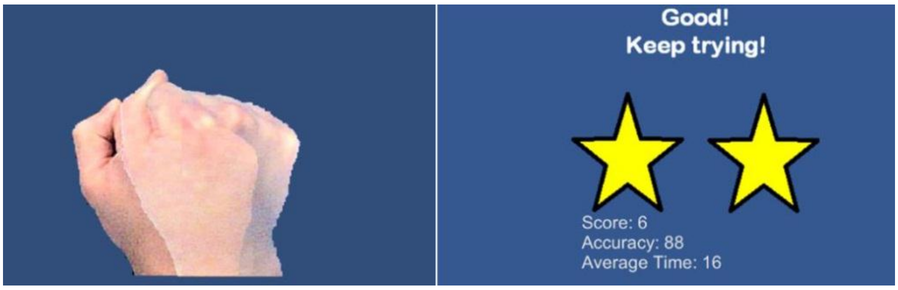
ABSTRACT

The use of Virtual and Augmented Reality (VR/AR) in physical rehabilitation can provide better control, improved user motivation, and flexibility in how therapy is offered. Mirror therapy is a therapeutic intervention that has been shown to be beneficial for upper limb stroke rehabilitation. However it requires, in its clinical application, the constant presence and attention of a skilled therapist who provides instructions. This paper presents an AR mirror therapy system that provides automatic instructions and feedback. A within-subjects design user study with healthy volunteers was conducted to evaluate the usability (System Usability Scale), perceived suitability (Suitability Evaluation Questionnaire for Virtual Rehabilitation Systems), satisfaction (subset of Usability Satisfaction Questionnaire), general experience (Mixed Reality Experience Questionnaire) and participants' performance and preference. We compared two conditions where the system automatically instructed the participants and (i) where the system additionally provided feedback, or (ii) the system did not provide feedback. All participants were able to complete the automated mirror therapy intervention. Participants significantly rated the usability and suitability of the automated intervention as positive. The comparisons between the two conditions on user experience and satisfaction indicated preferences for the feedback condition; however it was not statistically significant. In the direct comparison between systems, participants showed a strong and significant preference for the feedback condition. A few participants reported a mild level of discomfort attributed to the sitting position, exercises and placement of their hands on the table. With this study, further progress towards an automated system for the provision of mirror therapy was achieved and successfully evaluated with healthy participants. Preparations for clinical evaluations using this automated system with patients suffering from motor impairments after stroke can now commence.



The half-transparent image of the exercise and the actual hand of the user (left), post-phase feedback (right).

Pinches, J, and Hoermann, S (2016), Evaluating automated real time feedback and instructions during computerized mirror therapy for upper limb rehabilitation using augmented reflection technology, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 241–249, Los Angeles, California, USA, 20–22 Sept. 2016.

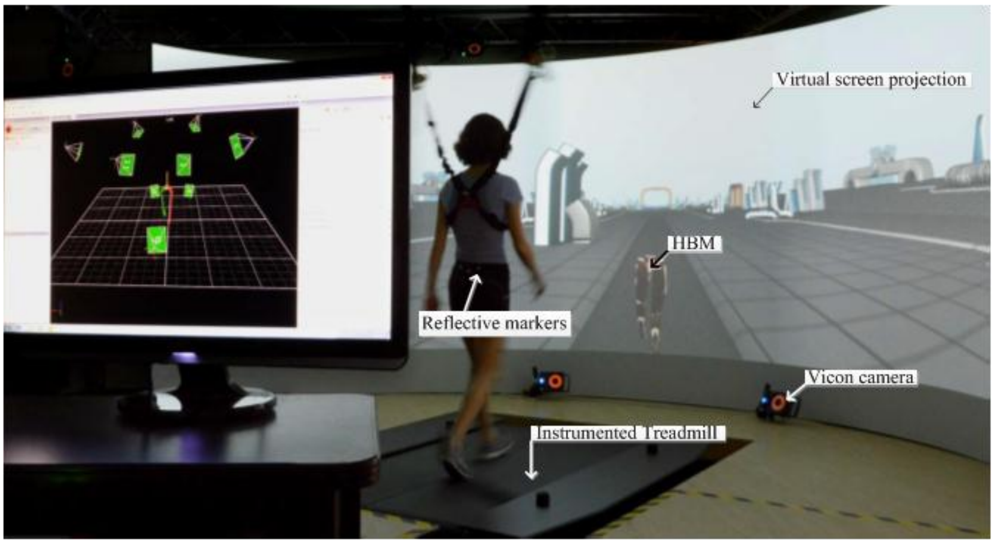
Augmented feedback approach to double-leg squat training for patients with knee osteoarthritis: a preliminary study

M Al-Amri, J L Davies, P Adamson, K Button, P Roos, R van Deursen

Cardiff University/Cardiff and Vale UHB, UK/CFD Research Corporation, Huntsville, AL, USA

ABSTRACT

The aim of this preliminary study was to explore the effects of two types of augmented feedback on the strategy used by healthy participants and patients with knee osteoarthritis (OA) to perform a double-leg squat. Seven patients with knee OA and seven healthy participants performed three sets of eight double-leg squats: one without feedback, one with real-time kinematic feedback and one with real-time kinetic feedback. Kinematic and kinetic outcome measures (peak knee flexion angle, peak knee extensor moment, and symmetry of the support knee moment between the injured and non-injured knees) demonstrate the potential influence of real-time kinetic feedback on the motor strategy used to perform a double-leg squat in both groups. This feedback could be used to develop more efficient and effective motor strategies for squatting in patients with knee OA and further evaluation is warranted.



Cardiff Gait Real-time Analysis Interactive Lab.

Al-Amri, M, Davies, JL, Adamson, P, Button, K, Roos, P, and van Deursen, R (2016), Augmented feedback approach to double-leg squat training for patients with knee osteoarthritis: a preliminary study, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 251–257, Los Angeles, California, USA, 20–22 Sept. 2016.

Session VIII: Stroke/General Rehabilitation

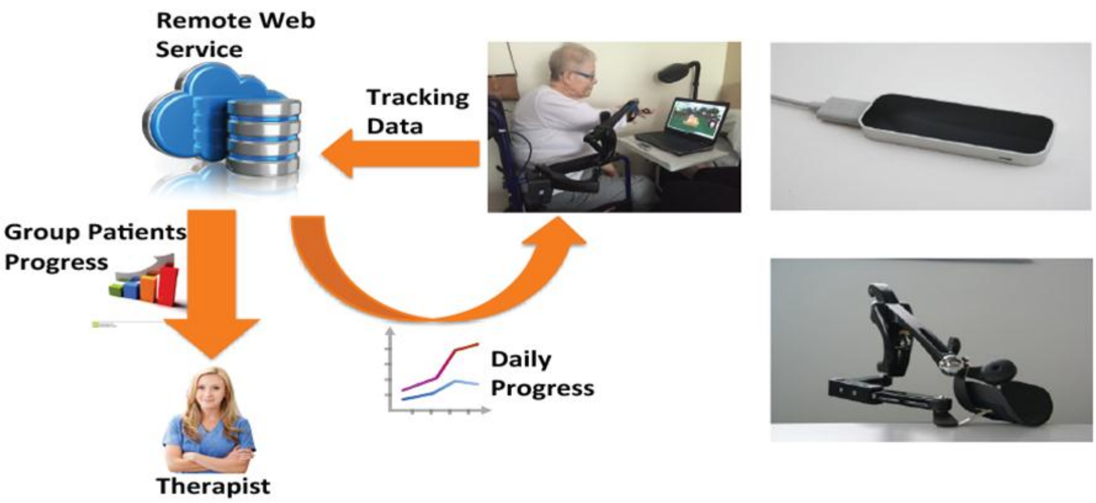
Home based virtual rehabilitation for upper extremity functional recovery post-stroke

Q Qiu, A Cronce, G Fluet, J Patel, A Merians, S Adamovich

Rutgers University/New Jersey Institute of Technology, University Heights, Newark, NJ, USA

ABSTRACT

After stroke, sustained hand rehabilitation training is required for continuous improvement and maintenance of distal function. An ideal home-based telerehabilitation system has to be low cost, easy to set up, effective in motivating the user to use it every day, generate progress reports to the user for self-tracking, and provide daily monitoring to remote clinicians. In this paper, we present a system designed and implemented in our lab: the NJIT Home-based Virtual Rehabilitation System (NJIT HoVRS). A single subject proof of concept study was conducted and demonstrated that this system is easy to access and effective in motivating subjects to train at home.



Left: RAVR-Home architecture design. Upper right: Leap Motion Controller. Lower Right: Armon Edero™ arm support.

Qiu, Q, Cronce, A, Fluet, G, Patel, J, Merians, A, and Adamovich, S (2016), Home based virtual rehabilitation for upper extremity functional recovery post-stroke, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 259–265, Los Angeles, California, USA, 20–22 Sept. 2016.

Short Papers ~ Abstracts

Kinect controlled game to improve space and depth perception, **D Bekesi**, **C Sik-Lanyi**, University of Pannonia, HUNGARY

Space perception is one of the most important skills of human life. Space perception is not a congenital faculty of human beings, but it evolves during the first few years of life. Experts are of the opinion that depth perception can be improved during the first 15-16 years of life. It is essential to perform depth perception in several occupations. We have developed virtual reality game with animations that were used by students to practice space perception tasks and to acquire better space perception. The game is controlled via Kinect sensor.

Bekesi, D, and Sik-Lanyi, C (2016), Kinect controlled game to improve space and depth perception, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 267–270, Los Angeles, California, USA, 20–22 Sept. 2016.

Influence of point of view and technology in presence and embodiment, **B A Borrego**, **J Latorre**, **R Llorens**, **E Noé**, **M Alcañiz**, Universitat Politècnica de València/Fundación Hospitales NISA, Valencia/Univesity of Jaume I, Castellón, SPAIN

Presence and embodiment have been reported to modulate the experience in virtual worlds. However, while these perceptions are presumably interconnected, little research has been done to unveil the nature of this relationship. In this study we show how presence and embodiment are modulated by the point of view of a virtual body and the enabling technology while being engaged in a virtual task.

Borrego, BA, Latorre, J, Llorens, R, Noé, E, and Alcañiz, M (2016), Influence of point of view and technology in presence and embodiment, , *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 271–274, Los Angeles, California, USA, 20–22 Sept. 2016.

Application of a rehabilitation game model to assistive technology design, **J Boureaud**, **D E Holmes**, **D K Charles**, **S McClean**, **P J Morrow**, **S M McDonough**, University of Limoges, FRANCE/Ulster University, UK

Games are increasingly used by physiotherapists in rehabilitation and the gamification of rehabilitation processes is an increasingly common practice. A key motivation for injecting playful or gameful activities into rehabilitation is to enhance engagement for home rehabilitation exercises by making them more fun. Multi-disciplinary cooperation is important in designing gameful activities. However, system design and development can be challenging between software engineers, health professionals, and academics due to terminology and knowledge differences. Sometimes skill and knowledge levels are also not optimal within the team. In both cases a comprehensive Rehabilitation Game Model (RGM) built on established principles, with an associated tool, can facilitate an effective design process. Factors that can be missed without use of a structured process include the potential impact of symptoms and variation in user demographic, personality or interaction preference. Our RGM helps game designers put a greater focus on variations between people in designing rehabilitation games. In this paper we provide an overview of the RGM and extend it to include rehabilitation aspects. We apply it to upper arm stroke rehabilitation. We present a representation of the output from the RGM that can form the basis for advice and guidance to serious game designers of upper arm stroke rehabilitation games.

Boureaud, J, Holmes, DE, Charles, DK, McClean, S, Morrow, PJ, and McDonough, SM (2016), Application of a rehabilitation game model to assistive technology design, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 275–278, Los Angeles, California, USA, 20–22 Sept. 2016.

Case study using virtual rehabilitation for a patient with fear of falling due to diabetic peripheral neuropathy, **K E Carroll**, **D J Galles**, St. Mary's Medical Center, San Francisco/University of San Francisco, USA

The purpose of this case study is to report the effects of using virtual rehabilitation (VR) to facilitate improvement of gait stability and endurance in a patient recovering from diabetic neuropathy who also experienced fear of falling. Timed Up and Go (TUG) testing revealed objective improvements and the subject's gait appeared more stable and fluid. She reported increased confidence in walking and endorsed increased confidence on the Activity-specific Balance Confidence Scale (ABC). This study also establishes how VR games can be inexpensively made and tailored to specific therapy needs since games were made by undergraduate Computer Science students for credit.

Carroll, KE, and Galles, DJ (2016), Case study using virtual rehabilitation for a patient with fear of falling due to diabetic peripheral neuropathy, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 279–282, Los Angeles, California, USA, 20–22 Sept. 2016.

Application of invisible playground theory to assistive technology design for motivating exercise within activities of daily living, **G Chaponneau**, **D E Holmes**, **D K Charles**, **S McClean**, **P J Morrow**, **S M McDonough**, University of Limoges, FRANCE/Ulster University, UK

Regular exercise promotes safe mobility for people affected by stroke, multiple sclerosis, and other disability related health conditions. It is also important for the prevention of falls among older people. Recent research investigates the use of indoor technology such as virtual reality (VR) and games to support and motivate regular exercise. Other research considers the use of mobile and wearable technology to track and promote exercise within the home and outdoors. In this paper we propose an approach that uses ideas from both contexts to develop a more persistent connected health system for encouraging more enduring exercise associated behaviour change. We utilise gameful design principles and play research to blend home-based VR and Serious Games with wearable, mobile tracking and reminder system approaches that are integrated into activities of daily living. In particular, we utilise ideas about the Invisible Playground from play theory to frame our interactive multi-modal exercise system. Our hypothesis is that by establishing a gamified, information rich feedback loop between structured system based exercise indoors and tracked activities of daily living outdoors, that motivation to exercise regularly may be improved. In this paper we summarise key relevant literature, discuss the Invisible Playground, and present the system architecture, APPRAISER, which will be used for the system development.

Chaponneau, G, Holmes, DE, Charles, DK, McClean, S, Morrow, PJ, and McDonough, SM (2016), Application of invisible playground theory to assistive technology design for motivating exercise within activities of daily living, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 283–286, Los Angeles, California, USA, 20–22 Sept. 2016.

Visual elements influence on navigation in virtual environments, **C Croucher**, **V Powell**, **A Molnar**, **W Powell**, University of Portsmouth, UK

Virtual rehabilitation often incorporates an element of travel in a virtual environment. Whether patients are transported automatically through the environment, or whether they have navigational control, it is important to understand how the design of the environment itself can supply navigational cues, and how the processing of these cues may influence perception, behaviour and task performance. This paper explores the literature, which might inform application design, and presents a case study using a think-aloud protocol to explore the perception of users to visual cues within a running game. We conclude with some preliminary suggestions for positive and negative navigational cues.

Croucher, C, Powell, V, Molnar, A, and Powell, W (2016), Visual elements influence on navigation in virtual environments, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 287–290, Los Angeles, California, USA, 20–22 Sept. 2016.

Development of a low-cost upper limb rehabilitation system using BCI, eye-tracking and direct visual feedback, **A Duenser**, **D Rozado**, **B Howell**, **G Rosolen**, **M Callisaya**, **M Lochner**, **M Cochrane**, CSIRO, Hobart, AUSTRALIA/ Otago Polytechnic, Dunedin, NEW ZEALAND/University of Tasmania, Hobart/Swinburne University of Technology, Melbourne AUSTRALIA

We are developing a novel system to improve arm function in stroke patients who have no, or only residual upper limb movement. Such a system fills an important gap in treatment options for people with little-to-no upper limb movement after stroke, and for whom regular treatments often are unsuitable. The system provides real-time visual and proprioceptive feedback of the arm plus the ability for participants to steer the movement direction of the arm through an assistive movement platform. The patient controls the system by simply looking at stimuli and engaging in motor imagery. The patient gaze is monitored with an eye tracker and motor output intentions are monitored with an EEG-based brain computer interface. Stimuli are presented as games in order to create a motivating rehabilitation environment. In this paper we discuss our motivation and design of the system.

Duenser, A, Rozado, D, Howell, B, Rosolen, G, Callisaya, M, Lochner, M, and Cochrane, M (2016), Development of a low-cost upper limb rehabilitation system using BCI, eye-tracking and direct visual feedback, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 291–294, Los Angeles, California, USA, 20–22 Sept. 2016.

Human cognitive enhancement tested in virtual city environments, **I Fajnerova**, **L Hejtmanek**, **H Rydlo**, **J Motyl**, **I Oravcova**, **T Zitka**, **J Hranicka**, **J Horacek**, **E Zackova**, National Institute of Mental Health (NIMH), Klecany/University of West Bohemia, Plzeň, CZECH REPUBLIC

The presented study focuses on human cognitive enhancement (HCE). Our aim is to map the key moments in interfacing of biology and technology that have the capacity to strongly affect and transform cognitive processes, such as spatial memory and navigation. We hypothesize that long-term use of HCE technology, in our case Augmented Reality (AR) glasses, while navigating through real environment can elicit changes both in spatial memory performance and in brain activity, connectivity and morphology. The proposed experiment focuses on the effect of long-term use (10-12 weeks) of Smart glasses (Vuzix M100). We tested 25 healthy volunteers, who were required to use the Vuzix navigation software when navigating in daily life. Prior to the experiment and during the final 12th week all participants (25 experimental and 25 control subjects) underwent complex prospective evaluation. The following test battery was used in order to study the effect of AR glasses wearing on: 1) vision (Ophthalmology examination); 2) cognitive abilities (RBANS, CPT, TMT); 3) specific spatial abilities (e.g. Money Road Map test, Perspective Taking Test); 4) eye-movements (eye-tracking) in the route-following and way-finding navigation performance in complex virtual city environment; and 5) brain activity (fMRI navigation task in virtual city, resting state fMRI) and morphology (VBM, DTI).

Fajnerova, I, Hejtmanek, L, Rydlo, H, Motyl, J, Oravcova, I, Zitka, T, Hranicka, J, Horacek, J, and Zackova, E (2016), Human cognitive enhancement tested in virtual city environments, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 295–298, Los Angeles, California, USA, 20–22 Sept. 2016.

Remediation of cognitive deficit in neuropsychiatric disorders using virtual carousel task and episodic memory task, **I Fajnerova**, **K Sedlakova**, **V Vorackova**, **A Dorazilova**, **L Hejtmanek**, **A Plechata**, **M Rodriguez**, **K Vlcek**, National Institute of Mental Health (NIMH), Klecany, CZECH REPUBLIC

The impairment of cognitive functioning represents a characteristic manifestation in various neuropsychiatric disorders, such as schizophrenia (SZ). Previous studies demonstrated mild to severe deficit almost in all cognitive domains. Our results obtained in the virtual analogue of the carousel maze also demonstrate impairment of spatial memory and cognitive flexibility in schizophrenia patients. In addition, results of the episodic-like memory task (EMT) also support the hypothesis of episodic memory deficit in schizophrenia. The aim of the presented study is to improve these impaired cognitive functions using remediation methods based on similar methods in a complex virtual environment. The remediation plan will be presented together with preliminary data obtained in a small group of schizophrenia patients.

Fajnerova, I, Sedlakova, K, Vorackova, V, Dorazilova, A, Hejtmanek, L, Plechata, A, Rodriguez, M, and Vlcek, K (2016), Remediation of cognitive deficit in neuropsychiatric disorders using virtual carousel task and episodic memory task, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 299–302, Los Angeles, California, USA, 20–22 Sept. 2016.

Motion sickness related aspects of inclusion of color deficient observers in virtual reality, **D A Gusev**, **R Eschbach**, **T Westin**, **J Yong**, Purdue University, USA/Norwegian National University for Science and Technology, Gjøvik, NORWAY/Monroe Community College, Rochester, New York, USA/ Stockholm University, SWEDEN

Color blindness is one of the most common forms of disability. Virtual reality (VR) development has increased recently, and it is important not to exclude people with impairments or other limitations. Visually induced motion sickness (VIMS) can be worse due to color versus black, white and gray environments. Can non-color factors in dynamic environments be excluded by performing color deficiency impacted tasks and comparing them to the equivalent static and dynamic tasks performed by a color-sighted person? Would a color-based experiment causing VIMS produce different results for a color deficient observer (CDO)? This paper advocates a novel approach to color blindness and motion sickness in VR based on psychophysical experiments. The aim is to find solutions and develop recommendations that will improve accessibility of VR for the colorblind.

Gusev, DA, Eschbach, R, Westin, T, and Yong, J (2016), Motion sickness related aspects of inclusion of color deficient observers in virtual reality, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 303–306, Los Angeles, California, USA, 20–22 Sept. 2016.

Labyrinth game with Kinect control, **R Haas**, **V Szucs**, **C Sik-Lanyi**, University of Pannonia, HUNGARY

Stroke changes not only the patients' lives, but also those of their families. The improvement of the active movement of the upper limbs is of great importance after stroke, which helps regain self-sufficiency and the recovery of fine movements. One of the key elements is the development of the active movements of the arm and fingers. The aim of the Flash-based labyrinth game of the article is to develop these motor skills, and that the patients may become self-sufficient in their home environment, or capable of working by the end of the rehabilitation. The Labyrinth Game is focusing on the movement of arms and elbows, out of the 17 exercises of Wolf Motor Function Test's (WMFT) upper limb rehabilitation tasks. The game uses simple forms and colours, and contains understandable and useable menus for more efficient usability.

Haas, R, Szucs, V, and Sik-Lanyi, C (2016), Labyrinth game with Kinect control, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 307–310, Los Angeles, California, USA, 20–22 Sept. 2016.

Gaming for health: an updated systematic review and meta-analysis of the physical, cognitive and psychosocial effects of active computer gaming in older adults, **S C Howes**, **D Charles**, **K Pedlow**, **J Marley**, **A Matcovic**, **P Diehl**, **S M McDonough**, Ulster University, Newtownabbey/Coleraine, NORTHERN IRELAND

Active computer gaming (ACG) is method of enabling physical activity in older adults. This review aimed to determine the effect of ACG on health outcomes in older adults. Four electronic databases were searched to identify 24 eligible randomised controlled studies: 1049 participants; 72.2% female; mean age 78±5 years. Data were pooled for six outcomes, with small to moderate effects observed in favour of ACG for functional mobility and balance outcomes. A large effect was observed in favour of ACG for cognitive function. This review presents evidence that ACG is effective in improving physical and cognitive function in older adults.

Howes, SC, Charles, D, Pedlow, K, Marley, J, Matcovic, A, Diehl, P, and McDonough, SM (2016), Gaming for health: an updated systematic review and meta-analysis of the physical, cognitive and psychosocial effects of active computer gaming in older adults, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 311–314, Los Angeles, California, USA, 20–22 Sept. 2016.

Pirate adventure autism assessment app: a new tool to aid clinical assessment of children with possible autistic spectrum disorder, **E Jordan**, **W Farr**, **S Fager**, **I Male**, University of Sussex/Sussex Community NHS Foundation Trust, Haywards Heath/Cell Software Services, Brighton, UK

Diagnostic assessment of possible Autistic Spectrum Disorder requires multidisciplinary assessment incorporating information from various settings, including psychometric assessment of the child. The Pirate Adventure Autism Assessment App includes a number of these psychometric tests adapted into a pirate adventure storyline. Early experience, presented here, suggests the tool is a useful adjunct to parental history and school questionnaire obtained at initial clinic, in determining the need for the child to proceed to a full, time consuming, expensive, diagnostic assessment.

Jordan, E, Farr, W, Fager, S, and Male, I (2016), Pirate adventure autism assessment app: a new tool to aid clinical assessment of children with possible autistic spectrum disorder, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 315–318, Los Angeles, California, USA, 20–22 Sept. 2016.

Effects of reintroducing haptic feedback to virtual-reality systems on movement profiles when reaching to virtual targets, **M A Just**, **P J Stapley**, **M Ros**, **F Naghdy**, **D Stirling**, University of Wollongong, AUSTRALIA

Virtual reality (VR) has been shown to have significant impacts on the efficacy of rehabilitation, improving a patient's motivation and participation, as well as improving scores in functional assessments when used to enhance traditional therapy. However, movements in VR have been demonstrated to have significant differences in movement profiles whilst performing simple reaching tasks compared to their real counterparts. The lack of tactile perception in VR systems is often attributed to be one of the causes of these differences. Therefore, to investigate the degree to which the lack of haptic feedback impacts movement profiles in VR, we have reintroduced the sense of touch through vibration motors on the fingertips. Participants were required to reach to virtual targets, both with and without haptic feedback. Their movements were quantified using motion capture, and the virtual targets were rendered using the Oculus Rift. The motions to both targets were compared using a number of measures to characterize the velocity profiles. Preliminary results suggest that the reintroduction of haptic feedback improves performance based indicators in virtual reaching tasks, such as the time to complete a reach, and the stability of the reaching hand whilst touching the virtual target.

Just, MA, Stapley, PJ, Ros, M, Naghdy, F, and Stirling, D (2016), Effects of reintroducing haptic feedback to virtual-reality systems on movement profiles when reaching to virtual targets, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 319–322, Los Angeles, California, USA, 20–22 Sept. 2016.

Step in time: exploration of synchrony and timing correction in response to virtual reality avatars for gait re-training, **O Khan**, **I Ahmed**, **M Rahhal**, **T N Arvanitis**, **M T Elliott**, University of Warwick/University Hospitals Coventry and Warwickshire NHS Trust, UK

This study investigates the use of virtual reality avatars as exercise cues for retraining gait. A feasibility test was conducted by asking participants to step in time with the avatar viewed through a virtual reality headset. We observed that a temporal perturbation (a speeding up or slowing down of one step cycle) applied to the avatar resulted in a significant corrective response in participants' own step timing. If this response can extend to spatial perturbations, we suggest that virtual reality avatars have the potential to assist in the targeted rehabilitation of neuromuscular or other disorders and retraining of gait post-surgery.

Khan, O, Ahmed, I, Rahhal, M, Arvanitis, TN, and Elliott, MT (2016), Step in time: exploration of synchrony and timing correction in response to virtual reality avatars for gait re-training, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 323–326, Los Angeles, California, USA, 20–22 Sept. 2016.

Do user motivation and attention influence performance of a postural reaching task in a virtual environment?, **D Levac**, **A Kelly**, **M Polizzano**, **S Saffee**, Northeastern University, USA

Practice in a virtual environment (VE) can enhance motivation and attention, but the relationship between these constructs and motor skill acquisition requires exploration. This study evaluated the impact of motivation (as measured by the Intrinsic Motivation Inventory) and attention to a task-irrelevant visual distraction (as measured by proxy via recall) on performance of a postural reaching task in a 2D VE in 27 young adults. Higher motivation was associated with higher scores, while poorer attention to task was associated with lower scores. Findings suggest that motivation and attention can impact VE practice; subsequent research will include retention and transfer tests.

Levac, D, Kelly, A, Polizzano, M, and Saffee, S (2016), Do user motivation and attention influence performance of a postural reaching task in a virtual environment?, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 327–330, Los Angeles, California, USA, 20–22 Sept. 2016.

How do the perspectives of clinicians with and without virtual reality/active video game experience differ about its use in practice?, **D Levac**, **P Miller**, **S M N Glegg**, **H Colquhoun**, Northeastern University, USA/McMaster University/ Sunny Hill Health Centre for Children, Vancouver/University of Toronto, CANADA

Little is known about clinicians' perspectives on the use of virtual reality (VR) and active video games (AVGs) in rehabilitation. We undertook an online survey of VR/AVG experience and learning needs in a sample of 1068 physical therapists and occupational therapists practicing in Canada. Nearly half (47%) had clinical experience with at least one system. While both therapist groups identified challenges and barriers, experienced therapists highlighted VR/AVGs' potential to increase patient motivation and engagement. Respondents without experience identified new potential avenues for VR/AVG use. Findings from this study will inform the content of open-access knowledge translation resources hosted at www.vr4rehab.com.

Levac, D, Miller, P, Glegg, SMN, and Colquhoun, H (2016), How do the perspectives of clinicians with and without virtual reality/active video game experience differ about its use in practice?, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 331–334, Los Angeles, California, USA, 20–22 Sept. 2016.

Development of smart mobile phone application to monitor progress and wellness for Chronic Obstructive Pulmonary Disease patients, **S M McDonough**, **A Boyd**, **T Patterson**, **P McCullagh**, **I Cleland**, **C Nugent**, **M Donnelly**, **H Zheng**, **N Black**, Affiliations

A bespoke application (app), 'KeepWell', tuned to chronic obstructive pulmonary disease (COPD) self-management has been developed. The app facilitates goal setting, progress monitoring and personal reporting; features were informed by n=4 clinicians. Eight other clinicians tested usability by undertaking a list of interaction tasks and completing a usability questionnaire. Qualitative comments or problems experienced during the completion of each task were noted. Overall the participants reported high levels of usability. Features that scored consistently well were setting goals, self-reporting and viewing progress. Suggested changes were: setting and editing reminders and ensuring the manual information was consistent with the operation of the KeepWell app.

McDonough, SM, Boyd, A, Patterson, T, McCullagh, P, Cleland, I, Nugent, C, Donnelly, M, Zheng, H, and Black, N (2016), Development of smart mobile phone application to monitor progress and wellness for Chronic Obstructive Pulmonary Disease patients, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 335–338, Los Angeles, California, USA, 20–22 Sept. 2016.

Towards a novel biometric facial input for emotion recognition and assistive technology for virtual reality, **J T McGhee**, **M Hamedi**, **M Fatoorechi**, **D Roggen**, **A Cleal**, **R Prance**, **C Nduka**, Imperial College, London/Emteq Ltd, Brighton/Sussex University, Brighton, UNITED KINGDOM

Preliminary work using facial EMG to identify facial expressions is reported in this paper. Ten subjects performed 14 different facial expressions following an agreed protocol. Facial EMG signals, measured from surface electrodes, were processed and analysed using a machine learning algorithm. Our system is able to differentiate facial expressions for assistive input to a high degree of accuracy (99.25%) and posed emotional responses with 100% accuracy. We conclude facial EMG technology has the potential for both assistive input and emotion detection and could replace conventional assistive input devices or video based techniques for use with VR technologies.

McGhee, JT, Hamedi, M, Fatoorechi, M, Roggen, D, Cleal, A, Prance, R, and Nduka, C (2016), Towards a novel biometric facial input for emotion recognition and assistive technology for virtual reality, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 339–342, Los Angeles, California, USA, 20–22 Sept. 2016.

Physical therapists' opinion regarding the creation of a new virtual game to treat pelvic floor muscles dysfunction amongst children of school age, **M C Moreira**, **A Lemos**, Federal University of Pernambuco, Recife, PE, BRAZIL

The study aimed to investigate physical therapists' feedback regarding important points that should be added to a new virtual game application which will treat lower urinary tract dysfunction among children. This study used a questionnaire answered by ten physiotherapists, where the majority (80%) considered positively the idea of creating an application, while only 40% use technological devices in rehabilitation. With regards to observing patients progress, the majority (70%) reported a lack of tools that motivate the patient was the biggest problem. Based on that, we concluded that motivating tools are necessary to assist in pelvic floor treatment.

Moreira, MC, and Lemos, A (2016), Physical therapist´s opinion regarding the creation of a new virtual game to treat pelvic floor muscles dysfunction amongst children in school age, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 343–346, Los Angeles, California, USA, 20–22 Sept. 2016.

Mobile application to increase consciousness and strengthening of the pelvic floor muscles, **E C Moretti**, **M C Moreira**, **A E S P Souza**, **A Lemos**, Federal University of Pernambuco – UFPE, Recife, PE, BRAZIL

This research included the development of a computer interface for capturing electromyography signals via Bluetooth enabling the transmission of data to mobile devices combined with a specific virtual gaming application to investigate the biomechanical characteristics of the pelvic floor muscles. The capture of data is performed via electrodes placed at specific anatomic pelvic floor sites. The game was designed based on the evidence available on consciousness and strengthening of the pelvic floor muscles, in addition to coordinating training of the muscles at different levels of demand, according to each user.

Moretti, EC, Moreira, MC, Souza, AESP, and Lemos, A (2016), Mobile application to increase consciousness and strengthening of the pelvic floor muscles, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 347–450, Los Angeles, California, USA, 20–22 Sept. 2016.

Kinect sensor controlled game for early diagnosis of visual problems, **R Nemeth**, **V Szucs**, **C Sik-Lanyi**, University of Pannonia, HUNGARY

A serious game was designed for early (preschool-aged) vision-test at home or in kindergartens. It was created with Windows Presentation Foundation framework. This framework is a good choice for developing vision-test game modules, as they can be easily accessed from one main application. The game module is a “Drag and Drop” game, which can be controlled with Kinect v2 sensor. The game is designed to take various objects along the tracks to the suitable finish goal. This type of game will help the user discover visual acuity problems. The game monitors that how long it takes to complete the track with different difficulty settings, while storing the results.

Nemeth, R, Szucs, V, and Sik-Lanyi, C (2016), Kinect sensor controlled game for early diagnosis of visual problems, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 351–354, Los Angeles, California, USA, 20–22 Sept. 2016.

Development and validation of haptic interface for deaf-blind horseback riding, **M Ogrinc**, **I Farkhatdinov**, **R Walker**, **E Burdet**, Imperial College, London/Shadow Robot Company Ltd, London, UNITED KINGDOM

We present a haptic interface to help blind and deaf-blind people to practice horse riding as a recreational and therapeutic activity. Horseback riding is a form of animal assisted therapy which can improve self-esteem and sensation of independence. It has been shown to benefit people with various medical conditions including autism. However, in the case of deaf-blind individuals a therapist or an interpreter must stand by at all times to communicate with the rider by touch. We developed a novel and low cost interface which enables blind and deaf-blind people to enjoy horseback riding while the instructor is observing and remotely providing cues to the rider, which improves their independence. Initial tests of the concept with an autistic deaf-blind individual received very positive feedback from the rider, his family and therapist.

Ogrinc, M, Farkhatdinov, I, Walker, R, and Burdet, E (2016), Development and validation of haptic interface for deaf-blind horseback riding, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 355–357, Los Angeles, California, USA, 20–22 Sept. 2016.

Eyeblink rate during a virtual shopping game performance for cognitive rehabilitation, **S Okahashi**, **R Watanabe**, **Z Luo**, **T Futaki**, Kyoto University/Kobe University, JAPAN

We developed a virtual shopping game having four levels using virtual reality technology for realistic cognitive rehabilitation. The objective of this study was to investigate characteristics in eyeblink rate in relation to task difficulty level. Six healthy adults were asked to buy two specific items in level 1, four items in level 2, six items in level 3, and eight items in level 4 at a virtual mall. Shopping items were daily necessaries which were independent of each other. Task performance, subjective assessments, and eye blinks during the game performance were recorded. As a result, the mean numbers of movements buttons used and the mean time required were higher/longer in level 4 than in level 1. The average subjective assessment scores were higher in level 4 than in level 1. Although the transitions of eyeblink rates were individually different, there was no statistical difference between phases, there were some relationships between subjective assessments and eyeblink rates. It suggests that eyeblink rate could be an index that reflects psychological aspects.

Okahashi, S, Watanabe, R, Luo, Z, and Futaki, T (2016), Eyeblink rate during a virtual shopping game performance for cognitive rehabilitation, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 359–362, Los Angeles, California, USA, 20–22 Sept. 2016.

Nicotine-enhanced responding for chocolate rewards in humans, **A N Palmisano**, **E Hudd**, **C McQuade**, **H De Wit**, **R S Astur**, University of Connecticut, Storrs, CT/University of Chicago, IL, USA

Despite an abundance of evidence illustrating the harmful effects of nicotine use, only a small percentage of users successfully quit. Moreover, current treatments for nicotine cessation produce only a slight increase in the likelihood of successfully quitting, which emphasizes the need for more effective strategies that facilitate smoking cessation. Several studies suggest that difficulty in controlling nicotine use behaviors results from nicotine's ability to enhance the motivating function of cues associated with obtaining rewards. In order to better understand the reward mechanisms that underlie the risk for becoming dependent, the aim of the current study was to examine nicotine's effects on conditioning, extinction, and reinstatement in humans. Using a novel virtual reality translation of the hallmark conditioned place preference paradigm to investigate the aforementioned objectives, our main findings suggest that nicotine (1) increases the sensitivity of reward properties by enhancing the strength of food-reward conditioning, (2) delays the rate of extinction of conditioned preferences, and (3) increases the reinstatement of previous conditioning.

Palmisano, AN, Hudd, E, McQuade, C, De Wit, H, and Astur, RS (2016), Nicotine-enhanced responding for chocolate rewards in humans, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 363–366, Los Angeles, California, USA, 20–22 Sept. 2016.

Face tracking training in children with severe motor impairment: case report, **A Pasquale**, **L Morgia**, **F Cappelli**, **C Vignati**, **E Pasquale**, **S Gazzellini**, **M Sabbadini**, **S Staccioli**, **E Castelli**, OBPG, Roma/IRCCS S. Raffaele, Roma/Sapienza University, Roma ITALY

The article reports an interactive training experience in children with tetraplegia using a face tracking system. Classic assessment scale and specific interactive tasks were used to evaluate and carry out the treatment based on a multimodal approach. The aim of the training was to improve lateral head rotation and oral motor ability with a specific interactive patch connected to the head and face movement. Finally, further trajectory movements and computer control by means of face movement were evaluated. From a descriptive point of view the system proved to be a functional tool to help subjects with severe motor impairment and it empowered the use of their residual functional movements.

Pasquale, A, Morgia, L, Cappelli, F, Vignati, C, Pasquale, E, Gazzellini, S, Sabbadini, M, Staccioli, S, and Castelli, E (2016), Face tracking training in children with severe motor impairment: case report, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 367–370, Los Angeles, California, USA, 20–22 Sept. 2016.

Process and feedback oriented platform for home-based rehabilitation based on depth sensor technology, **A Ridderstolpe**, **J Broeren**, **G Clemons**, **J Jalminger**, **L-Å Johansson**, **M Johanson**, **M Rydmark**, Alkit Communications, Mölndal/The Sahlgrenska Academy, University of Gothenburg, SWEDEN

In this paper a game-based rehabilitation platform for home usage, supporting stroke and chronic obstructive pulmonary disease (COPD) rehabilitation is presented. The main goal is to make rehabilitation more enjoyable and easily accessible for the patients. The platform provides facilities for creation of individualized plans for each patient with a program of game-exercises planned by the patient's caregiver through a web-based planning service. The games are based on specific motion patterns designed in collaboration with rehabilitation specialists. Motion regulations and guidance functions are implemented specifically for each exercise to provide feedback to the user and to ensure proper execution of the desired motion pattern. The caregiver can follow the progression of the rehabilitation and interact with the patient by video conferencing through the web-based service.

Ridderstolpe, A, Broeren, J, Clemons, G, Jalminger, J, Johansson, L-Å, Johanson, M, and Rydmark, M (2016), Process and feedback oriented platform for home-based rehabilitation based on depth sensor technology, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 371–374, Los Angeles, California, USA, 20–22 Sept. 2016.

Comparison of Wii Balance Board and force platform (baropodometry) for the evaluation of plantar pressures among healthy subjects, **A E S P Souza**, **A A L Carneiro**, **L H A N Dutra**, **M C Moreira**, **R M A Cunha**, Federal University of Pernambuco – UFPE, Recife, PE, BRAZIL

This study aimed to compare the use of Wii Balance Board® (Nintendo) with a baropodometer (force platform) to evaluate plantar pressure on healthy individuals. We also analysed the reliability of both platforms and found that, in addition to not being able to validate the data between the two platforms, there not was also a good reliability index in either of the two devices.

Souza, AESP, Carneiro, AAL, Dutra, LHAN, Moreira, MC, and Cunha, RMA (2016), Comparison of Wii Balance Board and force platform (baropodometry) on evaluation of plantar pressures among healthy subjects, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 375–378, Los Angeles, California, USA, 20–22 Sept. 2016.

Reducing impact of stress in patients with psychiatric disorders – a pilot study on the effects of swimming with wild, free dolphins in virtual reality, **W Veling**, **M J Sjollema**, **B C Brada**, University Medical Center Groningen/The Dolphin Swim Club, Leeuwarden, THE NETHERLANDS

In this pilot study, a 360° video VR relaxation program (VRelax) is being developed in order to reduce the impact of stress in patients with depressive, anxiety and psychotic disorders. The relaxing effect of an underwater VR experience with wild, free dolphins will be compared to the effect of an VR experience with natural surroundings such as beach, open fields and dunes and to a 2D experience with video clips of natural surroundings.

Veling, W, Sjollema, MJ, and Brada, BC (2016), Reducing impact of stress in patients with psychiatric disorders – a pilot study on the effects of swimming with wild, free dolphins in virtual reality, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 379–382, Los Angeles, California, USA, 20–22 Sept. 2016.

Can visual stimulus induce proprioceptive drift in the upper arm using virtual reality?, **D Willis**, **V Powell**, **B Stevens**, **W Powell**, University of Portsmouth, UK

Sustained isometric contractions (SIC), such as holding an arm stationary in a space, are often used in upper limb rehabilitation exercises, particularly where it is important to protect the joints and tendons or to reduce patient fatigue. However, visual cues within a virtual environment may have an unanticipated effect on the ability to maintain SIC. This study investigated the influence of background motion within a virtual environment on the ability to maintain a fixed position during an upper limb task. It was found that introducing directional movement had a significant differential effect on the ability to maintain SIC.

Willis, D, Powell, V, Stevens, B, and Powell, W (2016), Can visual stimulus induce proprioceptive drift in the upper arm using virtual reality?, *Proc. 11th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, AA Rizzo (Eds), pp. 383–386, Los Angeles, California, USA, 20–22 Sept. 2016.

Laval Virtual Vision 2025
Blurring the lines between digital and physical worlds

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ABSTRACT

The recent evolution of immersive technologies, such as Virtual Reality (VR) and Augmented Reality (AR) as well as Mixed Reality (MR), leads to the emergence of new immersive experiences occurring in blended spaces constituted of both digital and physical worlds. This paper, based on the outcomes of the first edition of the Laval Virtual Seminar on Vision 2025, explores Immersive Virtual Environments (IVE), its related technologies, and more particularly addresses the potential increase of the immersion quality. It also discusses the main IVE elements and tries to foresee their key challenges and needs towards envisioned future developments.

1. INTRODUCTION

Recently, new immersive devices for VR applications, from very cheap cardboard head-up display style or other smartphone headsets up to more sophisticated but still pricey Head Mounted Displays (HMDs), pave the way toward democratizing immersive 360° experiences for every organization and consumer. Effectively, while several million of cardboard sets have already been distributed to early experimenters of VR applications, only thousands of new VR HMDs have been launched for developers and early adopters, such as gamers. The same applies to AR glasses, though, there isn't yet anything very cheap and it seems that the price depends on the capacity to display holograms overlaying objects on a real environment. Large media players and big brands already offer content and brand new immersive VR experiences for free reaching a large public that immediately get the 'wow' effect of being present in the middle of a story world instead of watching a video on a flat screen. The persuasive power of 360° experiences in immersive worlds will push organizations and people to soon be willing to pay for consuming more content and live new exciting immersive VR experiences.

Figure 1. *Laval Virtual 2016 – www.laval-virtual.org.*

Anyone visiting Laval Virtual (LV) exhibition this year (Figure 1) could easily observe the growing enthusiasm of visitors fighting on the booths having available HMDs for experiencing 360° VR immersion. Laval Virtual is now the largest European show in the field of immersive technologies (VR, AR, MR) with 145 exhibitors and 15,500 visitors in 2016. This year, LV inaugurated the "Laval Virtual Seminar on Vision 2025", a prospective seminar that brings together international experts in immersive technologies and future industries. Its first edition has been held on 2016 March 21-22 at the 'Chateau de la Mazure', near the city of Laval, France. The invited "Visionaries" (Figure 2) worked together to foresee and imagine the future of immersive technologies and then create elements of a common "Laval Virtual Vision 2025". On the third day, March 23rd, which is also the opening day of the Laval Virtual exhibition and ACM VRIC'2016 conference, they presented their views and shared vision elements to 150 specialists from diverse Academic research fields and Industry sectors. Multidisciplinary teams of these specialists worked together on the 4th day (March 24th) via thematic workshops to turn the prospective vision outcomes into specific future development aspects. A plenary session, which was held on Friday, March 25th, presented the contributions of these workshops to the LV Vision 2025.

Figure 2. *Laval Virtual Seminar 2016 visionaries – from left: Dr Marc Pallot, Dr Skip Rizzo, Dr Dirk Reiner, Dr Oliver Bimber, Dr Carolina Cruz-Neira, Georges Karvelis, Christine Perey, Alexandre Godin and Dr Simon Richir.*

This paper explores an IVE structure, discusses immersion quality and reports about the outcomes of the Laval Virtual Seminar (LVS'2016) on Vision 2025 whose main goal is to identify key challenges and needs that could pave the way toward VR, AR and MR developments from medium to long term future. Participants (see their names in the Acknowledgements) of this first LVS edition are affiliated to Academic research institutes or Industry business units. They are recognised experts in their respective fields of research or advanced technology deployment.

2. INCREASING THE QUALITY OF IMMERSION & PRESENCE

There are very relevant quotes from Albert Einstein when thinking about the meaning of the concept of immersion: "*Reality is merely an illusion, albeit a very persistent one*"; "*Truth is what stands the test of experience*" and finally "*Put your hand on a hot stove for a minute, and it seems like an hour. Sit with a pretty girl for an hour, and it seems like a minute. THAT'S relativity*".

If the phenomenon of immersion has the capacity to turn an illusion into a persistent one, then, it becomes a reality for people that believe in experiences they live; and, most probably, because they love engaging situations in which the notion of time disappears. A dictionary tells us that immersion represents the state of being deeply engaged; like being fully absorbed by playing sport, known as being a tactical/sensory-motoric immersion; or solving a problem, known as being a strategic/cognitive immersion; or reading a captivating story or watching an exciting movie, known as being a narrative/emotional immersion (Ernest, 2004; Staffan & Holopainen, 2004; Pillai & al., 2013). These types of immersion make one's brain so busy that everything else around simply disappears. A pretty good way to measure the deepness to which a person is engaged is to observe whether the notion of time disappears as well as the whole external world. To make it short, one could argue that a 360° VR immersion bubble operates like a mind-blowing teleportation, instantaneously transporting a user in an existing remote place or a different world that is persistent enough to become another reality, even if it is a virtual one.

While VR is considered fully immersive because the real surrounding environment disappears, AR and MR look partly immersive because users still see their real environment on which digital (virtual) objects are overlaid; hence, augmenting the reality. Furthermore, MR provides the capacity to scan real objects or parts of the real environment and bring them into the digital (virtual) world; hence, augmenting also the virtuality.

Another consideration about immersive technologies, consists in making a distinction between passive immersion, seating and watching a 360° spherical scene wearing a HMD, and active immersion, almost freely walking in a 360° scene like in a Cave Automatic Virtual environment (CAVE) (Cruz-Neira et al., 1992) equipped with head and motion tracking. Cruz-Neira and colleagues (1992) have defined five main factors enhancing the quality of immersion in a CAVE, namely: 1) a view-centered perspective (head tracking), 2) panorama (surrounding the viewer with visuals), 3) body and physical representation (users' awareness of the interactive workspace's physical constraints), 4) intrusion (restricting the user's senses), 5) the field-of-view (the display portion users can observe without rotating their head, maximum 180°, practically 120°). From affordability point of view, there is a considerable cost difference between a HMD and a CAVE; though, nowadays, there are low cost CAVE solutions available on the market.

According to Cummings and Bailenson (2015), technologies to achieve quality immersive mediated environments are becoming more affordable, for example surround-screen VR display (Cruz-Neira et al., 2010), and less cumbersome. In fact, immersive technologies are intended to stimulate senses of users in a way that they feel present in a mediated virtual environment (Heeter, 1992; Gaggioli et al, 2003). The quality of the mediated immersion or Immersive Virtual Environments (IVE) relies on the number of stimulated senses, namely: vision (e.g. HMD, CAVE, and holographic display), auditory (e.g. surrounding sound) and tactile (e.g. haptic devices). They constitute the most frequently stimulated senses. The quality of the mediated immersion depends also on the user provided capacity to naturally interact and evolve (e.g. motion tracking, gesture recognition, omnidirectional treadmill) in such a virtual environment. Olfaction and gustation senses, are more rarely in use in IVE due to the fact that it is not necessarily mandatory to spread artificial flavors around and quite costly to realize for a limited increase of the immersion quality. Nevertheless, the stimulation of these two senses could become much more important depending on the nature of the immersive experience to be designed (e.g. perfume or wine based applications). However, the above-mentioned tactile sense depends on the somatosensory system that allows humans to experience different sensations, such as: touch, pressure, temperature, pain, posture (spatial location of body parts) and facial expression collectively called proprioception. Other sensations like movement, acceleration and balance depend also on the vestibular system (Brynie, 2009; Krantz, 2009). These sensations are often in play in the case of immersive training simulators delivering more effective trainings for accelerated and experiential Learning (Reiners, 2008), and exergame simulators for learning specific sport activities, such as jogging, golfing and skiing, by practicing in a social environment with indoor and outdoor players having different level of expertise (Pallot et al., 2013).

Immersive technologies often play with illusions like the 3D vision supported by stereoscopic display and glasses (passive or active) that provide a depth perception as an illusion of depth beyond the screen. Most of the stereoscopic approaches are based on two images separately sent to the user's left eye and right eye. The user's brain assembles these 2D images in order to get an illusion of 3D depth. Another type of immersive technology conveying a 3D visual illusion is the holographic display that doesn't necessitate wearing any glasses. The main consequence of playing with illusion is that it engenders brain or visual tiredness and sometimes even diffraction sickness that make the immersive experience uncomfortable. This is due to the constant brain adaptation when receiving contradictory stimulus from several senses. For example, a user is seated while playing a car race, in the scene the car is moving; hence, the brain should balance contradictory raw data during the multisensory integration process. In this case, the contradictory stimuli are on the one hand a visual and audio perceived motion and on the other hand a proprioception/vestibular perceived motionless. In contrast, the LightField (LF) technology is promising for both displays and imaging systems because LF is fully compatible with the natural human vision capabilities. According to Birklbauer and Bimber (2014), LF photography becomes increasingly practical, LF cameras are already available on the market (e.g. Lytro, Raytrix); however, they explain that obtaining spatial and directional consistence is not yet systematic for avoiding strong image artefacts when refocusing and changing perspective

The quality of immersive technologies is also due to the capacity to track body parts or objects, such as head tracking in HMDs that captures the head position for rotating the field-of-view in a 360° scene. Field-of-view, frame-rate, resolution and latency factors, often mentioned as Quality of Service (QoS) (Wu et al., 2009), play an important role in the measurable technical quality of compelling immersive experiences. However, empirical findings have shown that a system excelling in the measurable QoS factors could still fail to convince users adopting it due to a low score of the perceived Quality of User Experience (QoE) (Davis, 1989; Wu et al., 2009) or other User eXperience (UX) dimension factors such as the social or societal dimension (Pallot and Pawar, 2012).

For designing IVE, it is of paramount importance to understand how humans perceive and comprehend the world surrounding them through their senses and felt sensations from multi-sensory modalities and integration (Stein et al., 2009; Light, 2009). According to Light (2009), humans' eye is a complex structure whose only a small part of its tissues are intended to the photoreception process leading to vision through the light emitted or reflected by objects that could be perceived in the visual environment. He claims that vision is a dominant sense for human beings as they rely more on vision than any other special sense. It is also necessary to anticipate IVE induced symptoms, such as motion sickness, vertigo, dizziness, visual tiredness and nausea (Lawson, 2014). In some cases, IVE could be reversely used for vestibular or other post-traumatic rehabilitation (Kruger, 2011; Rizzo et al, 2015). Cummings and Bailenson (2015) argue that the highest quality of immersion of the IVE, the more likely users will feel present in the IVE and will perceived the mediated environment as a plausible space in which they feel located (Wirth et al., 2007). Based on the definition of presence from Wirth et al. (2007), Cummings and Bailenson came to the conclusion that the concept of presence is a two-dimensional construct comprising the user sense of self-location and perceived opportunities to interact with the IVE.

Figure 3 presents a tentative IVE structure composed of an Immersive (VR/AR/MR) Platform, including the Immersive (3D) Content, delivering the Immersive Experience to users. The resulting users' perceived immersive sensations and feelings are then evaluated through measured and user perceived factors of the Immersion Quality. The quality of platform immersiveness is deducted from the measured QoS technical factors (e.g. field-of-view, frame-rate, resolution and latency factors) and QoE (e.g. ease-of-use, usefulness, presence) of the Immersive Platform. The degree of immersiveness depends on the main goal of the immersive application and on the selection of immersive technologies.

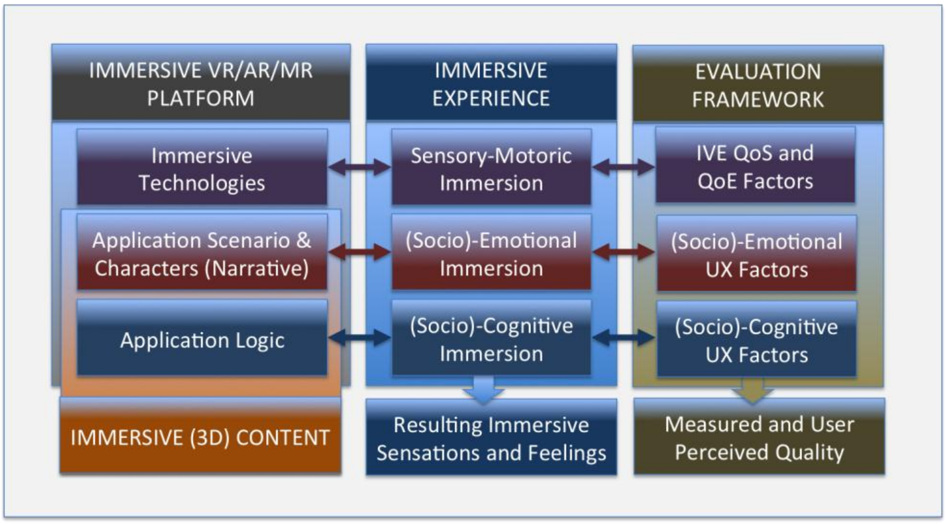

Figure 3. *Representation of an Immersive Virtual Environment (IVE).*

As for the evaluation framework of an immersive experience, the (socio)-emotional and (socio)-cognitive UX factors are envisioned in the Pallot et al (2013) extended QoE model of Wu (2009). For example, a ski training application could be a fully or partially immersive application. In the case of a fully immersive application, there are different possible technological solutions. It could be a VR based platform hosting a ski training application including a ski resort and skiing slopes 3D content for indoor ski practice (Figure 4). Hence, it is a fully immersive VR application that could be operated in a CAVE where the user wears stereoscopic 3D glasses, including head and gesture tracking, while practicing on a physical ski-training simulator animated by four hydraulic cylinders. Instead of using a CAVE, the user could simply wear a VR HMD. For sure, the cost is much lower with the HMD based solution compared to the one with the CAVE. Nonetheless, the resulting immersive experience will not necessarily be the same due to the physical environment blindness effect, which is generated when wearing the HMD, on the body movements for practicing on the physical ski simulator. The user's body responses, engendered by the perceptual layer as a reflex, for balancing the centre of gravity in order to avoid falling from the physical ski simulator depends on the received visual and vestibular-proprioception stimuli. While the visual stimulus is rather a perceived illusion as the user doesn't really move down the ski slope, the vestibular-proprioception stimuli look like real sensations due to the four hydraulic cylinders animating the physical ski simulator and transmitting the almost real feeling of the changing ski slope inclination including bumps. In our lab, we had to reverse the physical ski simulator in order to get the backside security bar that users can grab with their hands for preventing frontal falls. Otherwise, falling from the physical ski simulator is an extremely good indication of the user's level of immersion and engagement in the VR ski training activity.

In the case of a partially immersive application, the user simply see an avatar, controlled by a joystick, going down the ski slope in a VR application displayed on a flat screen. In another solution, the user wears ski AR goggles including head and motion tracking while practicing on a real ski slope. Hence, it is a partially immersive application because the user is still able to see the real surrounding environment while digital (virtual) objects are overlaid for adjusting body postures such as balancing the centre of gravity. Obviously, the resulting immersive experiences are not necessarily the same, especially from the sensory-motoric immersion point of view. While the quality of the sensory-motoric immersion will be lower compared to a fully immersive situation, the (socio)-emotional and (socio)-cognitive immersion could engender a higher immersion quality.

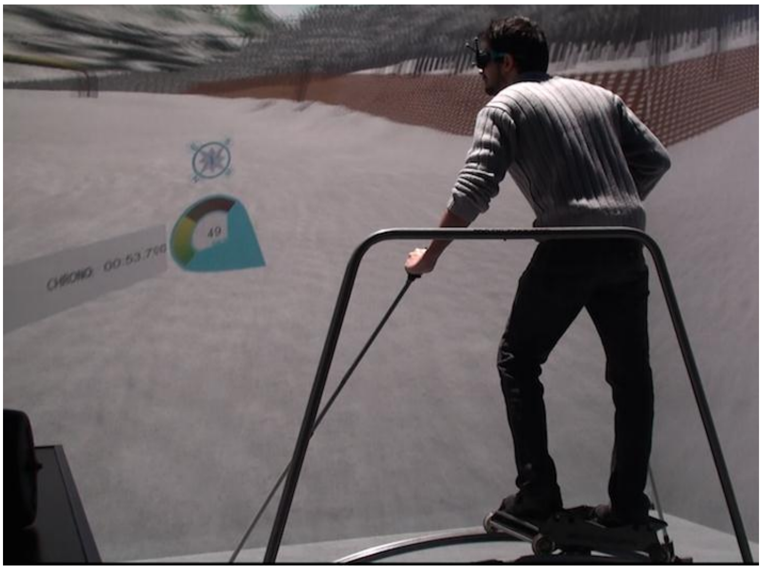

Figure 4. *3DLive European project – www.youtube.com/user/3DLIVEproject.*

3. KEY CHALLENGES

The first edition of the LV Seminar on Vision 2025, through brainstorming and world-café sessions, has allowed our working group to identify three Key challenges, namely: 1) improving the **quality of immersion** through the emergence of new immersive technologies; 2) easier creation of mind-blowing **immersive experiences**; 3) more natural **immersive platforms**.

3.1 Improving the Quality of Immersion

According to Cummings and Bailenson (2015), based on a meta-analysis of previous empirical work on immersive technologies and spatial presence for decades, tracking level, stereoscopy and field-of-view constitute the most prevalent features ensuring users feel physically present in IVEs. Participants of the LV Vision 2025 seminar have identified the following challenges to improve the immersion quality: 1) higher quality displays that reach human vision capabilities; 2) 4D imaging including enhanced tracking and 360° scene acquisition; 3) 4D displays including correct depth perception (accommodation);

These above described challenges imply the following needs:

- Increased display resolution for both small displays and projectors;
- Solve 3D disparity, convergence & accommodation, increased field of view (peripheral 120°);
- Promising light field displays with directional light per pixel;
- Possible for HMD but harder for large screens;
- Easy to realize with micro-lenses but needs extremely high resolution display;
- Other possible solutions, such as magic leap;
- High-resolution sensors.

3.2 Easier creation of immersive experiences

Participants of the LV Vision 2025 seminar have identified the following challenges to contribute to the easier creation of immersive experiences: 1) Wider Knowledge about Augmented, Virtual and Mixed Realities impact (human factors); 2) More accessible and reusable design of 3D & 360° content & experience; 3) Earlier ideas experimentation and continuous evaluation of user technology acceptance and solution adoption by users; 4) New skills & disciplines integrating multiple specialization (design, software, UI & UX, sensor engineering, art & gaming design).

These above identified challenges imply the following needs:

- Authoring Tools & New Skills;
- Guidelines for designing immersive (user) experience;
- Repository collecting good & bad examples of previous experiences;

- Automated XD quality check;
- Tools for rapid design & prototyping;
- Drag & drop approach with Lego style;
- Tools for experience evaluation;
- Device agnostic Tools, focus on UX and include behavior automation (AI);
- New curricula for Mastering immersive experiences (understand engagement, presence, motion sickness and complexity of interaction in 3D);
- New degrees & new job profiles.

3.3 More natural immersive platforms

Participants of the LV Vision 2025 seminar have identified the following challenges to contribute to more natural immersive platforms: 1) Higher immersive and sensing quality; 2) More accessible Design of human-tracking content & experience; 3) Automated behavior and user control; 4) Fulfill ethics, Security & privacy issues; 5) Wider Virtual human use cases.

These above identified challenges imply the following needs:

- Automated tutoring; virtual patient, companion, interviewer or coach; automated safety & quality control; teleportation, practice training;
- Authoring Tools for 3d agents (avatars or body reconstruction) with automated behavior (machine learning, database, persistence, range/domain, one-off);
- Authoring tools for designing virtual human use cases, the intensity of interaction, user control (pause/off/on) and user (immersive) experiences;
- Tools for sensing the real world with body gesture, hands & fingers motion, eye tracking, voice tone, contextual objects & space environment, physiological signals, facial emotions;
- Tools to design Natural User Interface;
- Tools to balance between technology, user and context (user experience);
- Imaging & physio tools for instant capture user environment and state of mind.

4. CONCLUSIONS AND FUTURE WORK

We explored a tentative IVE structure that could be operationalized and eventually standardized for whatever immersive VR, AR or MR applications. We also discussed the concept of immersion and related levels as well as notion of immersion quality that is included in the Evaluation Framework of this IVE structure. Finally, we presented the LVS'2016 identified key challenges and needs that will pave the way toward VR, AR and MR developments from medium to long-term future. It appears quite clearly that the Light-Field technology is an extremely promising 3D solution fully compatible with human vision capabilities for both displays and imaging systems that effectively capture and process 360° real scene (e.g. Lytro Immerge). Regarding other senses, there are new audio systems to capture and deliver 360° sound synchronised with the head tracking for delivering auditory space sensation in relation with the user's field-of-view. There are also new haptic technologies under development like an exoskeleton device for hands that delivers precise haptic feedback; a list is available on VR-Times (http://www.virtualrealitytimes.com/2015/03/13/list-of-haptic-controllers-virtual-reality/). The ultimate goal is to bring more stimuli for enhancing the immersive experience in order to make it more realistic.

Digi-Capital, a market advisor, forecasted in April 2015 that the VR/AR market will grow to $150B by 2020 and AR/MR devices (e.g. Hololens, Magic Leap) will replace the smartphone market because one could wear it anywhere and whatever the activity without obstructing the real environment or distracting from it; most probably, this forecast could come true when these partly immersive AR/MR devices will become lighter, closer to the natural humans' vision (e.g. Light-Field technology), social and privacy principles, as well as more affordable. In this forecast report, it was said "*AR, meanwhile, can be fun for games, but not as much fun as VR when true immersion is required*". In contrast, looking at the current success of the AR 'Pokémon GO' mobile-app location-based game (Figure 5), while the sensory-motoric immersion is mainly based on the dominant sense of vision for capturing virtual entities, its proved viral propagation is, most probably, rather due to the other two levels of Immersion than to its felt presence.

As for future work, up-coming LVS editions will allow to continuously refine the draft vision 2025 while introducing new emerging immersive technologies and approaches facilitating mind-blowing immersive experiences. An on-going second paper will report the contribution of the VRIC'2016 workshops to the first draft of the LV Vision 2025. We just started this fascinating LV Vision work as an open co-creation community assembling experts and specialists from different disciplines; we do not pretend to know what the future of immersive technologies (VR/AR/MR) is going to be but we do believe in what said Alan Kay (1971), "*The Best way to predict the future is to invent it!*".

The LVS second edition will be held on 2017 March 20-21 again at the 'Chateau de la Mazure', near the city of Laval, France; just before the opening day of the Laval Virtual exhibition and ACM VRIC'2017 conference and workshops that will be held from 22nd to 25th of March 2017. This second edition will bring an opportunity to further discuss and refine the outcomes of the first edition and to consider other emerging immersive technologies as well as new immersive/engagement approaches.

Figure 5. *Pokemon Go, great worldwide success of Augmented Reality technology.*

Acknowledgements: Authors wish to acknowledge their gratitude and appreciation to the LVS'2016 invited visionaries, namely (alphabetic order): Dr Oliver Bimber, Dr Carolina Cruz-Neira, Alexandre Godin, Georges Karvelis, Christine Perey, Dr Dirk Reiner, and Dr Skip Rizzo**,** for their valuable contributions to the success of the first edition of the Laval Virtual Vision 2025.

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Insights from 10 years of stroke virtual rehabilitation – a personal perspective

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During the last decade, the use of virtual reality (VR) for the rehabilitation of motor and cognitive deficits after stroke has became increasingly popular. This trend can be appreciated by the exponential growth over the years of the number of publications that evaluate, propose or review novel stroke rehabilitation and/or assessment paradigms based on the use of VR based technology. In 2006, we started the development of the Rehabilitation Gaming System (RGS), a pioneer VR based system in multiple aspects at that time. Besides some technical innovations – such as a non-invasive low-cost webcam-based motion capture system years before MS Kinect was developed – RGS had very specific mechanistic neuroscientific hypothesis on how VR could be further exploited to maximize stroke recovery. RGS exploited the embodiment of virtual agents, the effect of first-person perspective and Mirror Neuron activation as mechanisms for potentiating neuroreorganization. In addition, RGS was one of the first pushing forward the concept of a build-in adaptability engine to maximize training outcomes through an automated difficulty adjustment that individualized training parameters to patients (Cameirão, Badia, Oller, & Verschure, 2010). The impact of this system in comparison to standard rehabilitation was evaluated by a number longitudinal studies. In the most ambitious and demanding study that I ran, RGS was used in a 3-month intervention (plus 3 months follow-up) in acute stroke patients (Cameirão, Bermúdez i Badia, Duarte, & Verschure, 2011). The results of this study showed that VR based rehabilitation can have an acceleration effect in stroke recovery in the acute phase of stroke. Still nowadays there are not many studies of this kind because the implementation of such a protocol is very challenging and demanding. Nevertheless, controlled studies of this kind were (and are still) needed, and to date this is still one of my most important contributions to the field of virtual rehabilitation. In a later study with RGS, we compared the effect of using 3 different interface technologies (natural user interface, passive exoskeleton, and haptics) with 44 chronic stroke survivors on the same VR task (Cameirão, i Badia, Duarte, Frisoli, & Verschure, 2012). Results showed that the main contributor for the positive results were the VR scenario irrespective of interface technology. Further, retention of improvements on follow up was higher when a haptics interface was used, allegedly because of increased ecological validity in the interaction with the VR scenario.

More recently, I have been particularly interested in the context and content of rehabilitation tasks. One important aspect relates to how rehabilitation is delivered, and different features can be associated to approaches such as coaching or gaming (Cameirão, Smailagic, Miao, & Siewiorek, 2016). Additionally, it became apparent that VR motor rehabilitation approaches were not thoroughly considering all cognitive aspects of motor tasks. There is an increasing body of literature that advocates for a dual motor-cognitive training instead of the rehabilitation motor and cognitive skills separately. Hence, we started studying multiple aspects of integrative motor-cognitive VR rehabilitation. These range from the quantification of cognitive-motor interference based on patient profile or interface technology, use of computational modeling for task personalization, to the recreation of Activities of Daily Living (ADL) in more ecologically valid scenarios.

One interesting line of research is the study of the effect of using emotional content in a cognitive-motor VR rehabilitation task. It is known that emotional stimuli enhance attentional processes, and that such stimuli are recalled differently depending on their valence (neutral, positive, negative). Hence, we wanted to investigate how such premises could be integrated in a VR task for stroke cognitive rehabilitation, and understand what type of stimuli could be more adequate for attention and memory training. For this purpose, we ran a pilot eye-tracking study in which stroke survivors performed a virtual memory-attention task consisting on finding target images of different valence in a pool of distractors (Cameirão, Faria, Paulino, Alves, & Bermúdez i Badia, 2016). We analyzed how performance in the VR task, recall and eye gaze were modulated by the valence of the images. Our results indicate that stroke survivors are less attentive, present reduced visual search patterns and more false memories when negative stimuli are used in the VR task. These preliminary results emphasize the need of a careful consideration of the type of content being used in virtual scenarios as it impacts rehabilitation outcomes. Currently, we are conducting a controlled feasibility study with a similar cognitive-motor virtual reality task exploiting the use of positive stimuli based on the individual preferences of each user. We aim to evaluate the potential benefits of such a protocol in comparison to standard rehabilitation.

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Impact of combined cognitive and motor rehabilitation in a virtual reality task: an on-going longitudinal study in the chronic phase of stroke

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ABSTRACT

Stroke is one of the most common causes of acquired disability, leaving numerous adults with cognitive and motor impairments, and affecting patients' capability to live independently. Virtual Reality (VR) based methods for stroke rehabilitation have mainly focused on motor rehabilitation but there is increasing interest towards the integration of cognitive training for providing more effective solutions. In this work we present a VR cognitive and motor training task – the Reh@Task – and the preliminary results from an ongoing one-month longitudinal intervention. We show the results from twelve patients divided in two groups: experimental and control. Both groups were enrolled in conventional occupational therapy, which mostly involves motor training. Additionally, the experimental group performed a specific attention and memory training with the Reh@Task and the control group performed time-matched conventional occupational therapy. This VR-based task consists of performing adapted arm reaching movements and has difficulty progression levels implemented with guidelines from a participatory design study. We assessed the impact of both interventions post-treatment (4-5 weeks) and at 4 weeks follow-up through the Montreal Cognitive Assessment, Single Letter Cancellation, Digit Cancellation, Bells Test, Fugl-Meyer, Chedoke Arm and Hand Activity Inventory, Modified Ashworth Scale and Barthel Index. A within groups analysis revealed significant improvements with respect to baseline in the global cognitive functioning in both groups, but only the patients who used the Reh@Task improved significantly in attention and memory. With respect to the motor domain, the control group showed greater improvements. Nevertheless, both groups improved significantly in the functional recovery of the hand and arm scores, revealing that both interventions had an impact in the use of the hand and arm in the activities of daily living. Overall, results are supportive of the viability of tools that combine motor and cognitive training, such as the Reh@Task.

1. INTRODUCTION

1.1 *Cognitive and motor impairments after stroke*

Stroke is one of the most common causes of adult disability and its prevalence is likely to increase with an aging population (WHO, 2015). It is estimated that 33% to 42% of stroke survivors require assistance for daily living activities 3 to 6 months post stroke and 36% continue to be disabled 5 years later (Teasell et al., 2012). Upper-limb impairments, such as fine and gross motor control, muscle strength, and power loss are the consequences that have a greater impact on functional capacity, what makes its recovery important for minimizing long-term disability and improving quality of life (Saposnik, 2016). In fact, most rehabilitation interventions focus on facilitating recovery through motor learning principles (Kleim & Jones, 2008). However, learning engages also cognitive processes such as attention, memory and executive functioning, all of which may be affected by stroke (Cumming, Marshall, & Lazar, 2013). Still, conventional rehabilitation methodologies are mostly motor focused, although 70% of patients experience some degree of cognitive decline (Gottesman & Hillis, 2010), which also affects their capability to live independently (Langhorne, Bernhardt, & Kwakkel, 2011).

1.2 What is missing in conventional cognitive and motor rehabilitation methodologies?

Although rehabilitation strives to take advantage of neuroplasticity through the intensive repetition of specific learning situations during recovery (Saleh et al., 2011), conventional methodologies have not entirely accomplished this goal (Levin, Weiss, & Keshner, 2014). Currently, paper-and-pencil tasks are widely used in cognitive rehabilitation, and are assumed to be reliable and with adequate construct validity in the assessment and rehabilitation of cognitive functions (Wilson, 2013). However, this methodology is not suited to deliver immediate feedback and reinforcement on progress, which is an important element to increase the motivation and avoid dropouts (Parsons, 2015). Additionally, when the dominant arm is affected by hemiparesis, performing paper-and-pencil tasks may become difficult or impossible. Regarding the motor domain, the persistent repetition of motor actions can be demotivating due to its repetitiveness and, because it is labor and demanding in terms of human resources, it is not as intensive as it should be (Langhorne, Coupar, & Pollock, 2009).

In addition, the relationship between cognitive and motor deficits is increasingly being unveiled and cognitive effort appears to contribute to motor recovery (Mullick, Subramanian, & Levin, 2015). For instance, it was found that repeated performance of a movement may not lead to meaningful improvement unless the task is performed within the functional demands of a relevant environment (Levin et al., 2014). In fact, the practice of manipulations that require more cognitive effort were already predicted to be more effective for motor learning compared to those that require less cognitive effort (Hochstenbach, Mulder, Limbeek, Donders, & Schoonderwaldt, 1998). In this endeavor, it is important to investigate the learning potential of patients with post-stroke cognitive and motor impairments by developing new therapeutic strategies that merge cognitive and motor intensive training.

1.3 Virtual Reality as a tool for combined cognitive and motor rehabilitation

Virtual reality (VR) has emerged as a valuable approach in stroke rehabilitation by providing the opportunity to practice cognitive and motor activities in an ecological context, which is not possible within the clinical environment (Klinger, Sánchez, Sharkey, & Merrick, 2014). Such enriched training tasks can be used to provide meaningful motor repetitions in the context of cognitive rehabilitation tasks, together with immediate feedback, thereby maximizing motor learning (Laver, George, Thomas, Deutsch, & Crotty, 2015). These virtual environments have the potential to optimize motor learning by manipulating practice conditions that explicitly engage motivational, cognitive and sensory feedback-based learning mechanisms (Levin et al., 2014).

However, despite the interdependency between cognitive and motor domains, they have mostly been considered separately in the development of VR-based methodologies (Laver et al., 2015). We argue that novel VR tools should focus on integrative cognitive and motor rehabilitation based on tasks that pose both cognitive and motor demands. Assuming the interdependence between the recovery processes, we may provide a more effective rehabilitation tool. Here we present an ongoing longitudinal clinical trial, with the results of the first 12 patients with stroke: six performing a VR-based intervention and six performing conventional rehabilitation. The VR-based intervention, named Reh@Task, consists in the virtual adaptation of paper-and-pencil cognitive tasks to be solved with repetitive arm reaching movements. The Reh@Task automatically adapts the difficulty level according to the patient performance, which increases challenge and the patient’s optimal experience (Csikszentmihalyi & Csikszentmihalyi, 1992).

2. METHODS

2.1 Participants

Participants were recruited at the CMM – Centro Médico da Murtosa (Aveiro, Portugal), based on the following inclusion criteria: at least six months after first ischemic stroke; undergoing occupational therapy rehabilitation; no vision problems; no history of premorbid deficits; no neglect; capacity to read and write; no severe depressive symptomology as assessed by the Geriatric Depression Scale (Yesavage et al., 1982); non-aphasic and with sufficient cognitive ability to understand the task instructions as assessed by the clinicians. Patients who scored less than 28 in the elbow flexion and shoulder abduction tests from the Motricity Index (Paternostro-Sluga et al., 2008) were excluded. The sample consisted of twelve patients with stroke randomly distributed in two groups (Table 1). The experimental group comprised six (5 male, 1 female) senior (*M*=62.17 years old, *SD*=8.18) patients with stroke (2 right hemisphere, 4 left hemisphere), with an average of 32.17 ± 26.93 months post-stroke, a mean of 5.67 ± 2.07 years of schooling, and 2 out of 4 with self-reported computer literacy. The control

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group comprised six (4 male, 2 female) senior (*M*=76 years old, *SD*=6.63) patients with stroke (2 right hemisphere, 4 left hemisphere), with an average of 55.33 ± 47.35 months post-stroke, a mean of 3.83 ± .41 years of schooling and no one had self-reported computer literacy. The clinic's board of directors approved the study and all the participants gave previous informed consent.

Pairwise Mann-Whitney tests revealed no differences between groups in the demographic characteristics and in the cognitive assessment tests at baseline. Concerning the motor domain, there were differences between groups at baseline only in the Modified Ashworth Scale.

Table 1. *Experimental and control group demographics (Mean ± SD).*

	Experimental	**Control**
Age	62.17 ± 8.18	76 ± 6.63
Gender	5 male; 1 female	4 male; 2 female
Schooling	5.67 ± 2.07	3.83 ± .41
Time post-stroke	32.14 ± 26.93	55.33 ± 47.35
Stroke location	2 Right; 4 Left	2 Right; 4 Left

2.2 *Reh@Task for cognitive and motor training*

The Reh@Task was designed as an adaptation in VR of the Toulouse Piéron (TP) task (TP-VR) (Faria, Vourvopoulos, Cameirão, Fernandes, & Bermúdez i Badia, 2014), extended to incorporate numbers, letters and symbols. Reh@Task is a variation of cancellation tests used by conventional rehabilitation methodologies with the objective of training attention. Reh@Task also adds a memory variant by displaying the targets for an amount of seconds at the beginning and then hiding them in the target selection step. Figure 1a shows an illustration of the Reh@Task for attention training, where the targets are always visible. Figure 1b illustrates the memory variant, where the targets are displayed for a number of seconds and then disappear for the selection task. Figure 1c shows the different target elements used in Reh@Task ordered by increasing complexity.

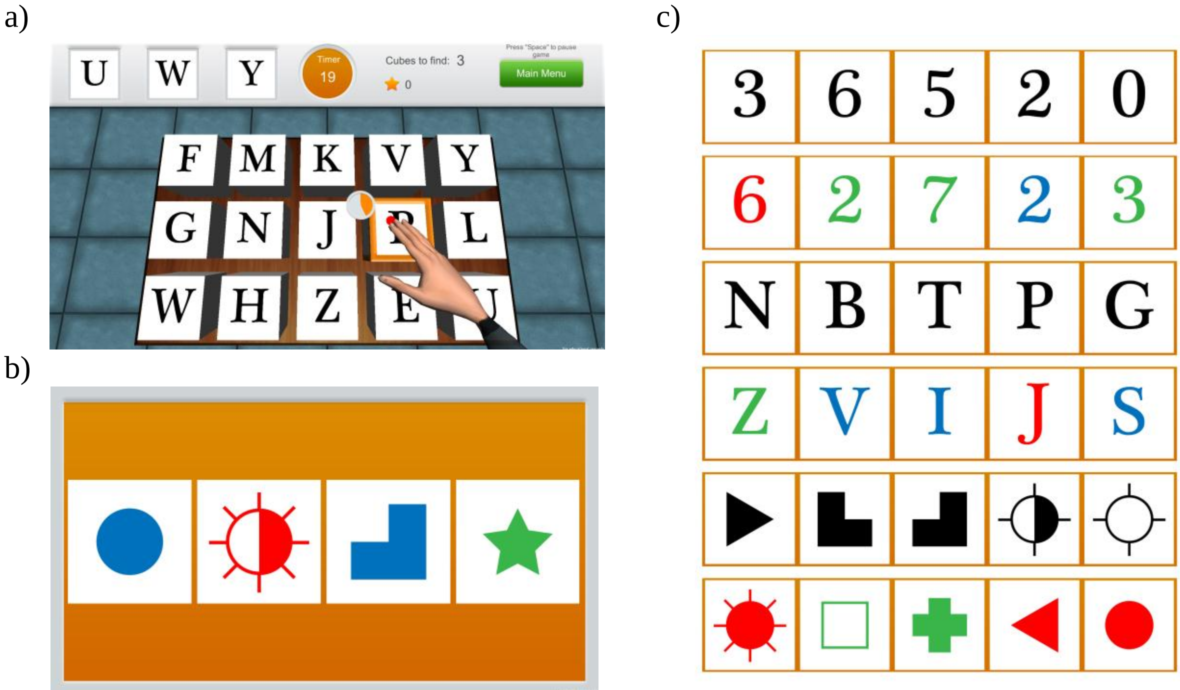

Figure 1. *Reh@Task subsets of stimulus.* ***a)*** *Attention training: cancellation task with black and white letters.* **b)** *Memory training: The target stimuli (symbols) are presented in the center of the screen and then disappear; the participant has to select them by memory.* **c)** *Target stimuli ordered by increasing complexity.*

Reh@Task is designed to be performed by repetitive arm reaching movements on a tabletop surface, and implemented by using the representation of the paretic arm for navigating and targeting symbols arranged in a three-dimensional environment. The target selection is made through a timer. The interaction with the computer is made through 2D arm movements with a camera-based Augmented Reality (AR) pattern tracking software (AnTS) (Mathews, Badia, & Verschure, 2007) (Figure 2). The VR environment has a built-in calibration function that is able to compute the active range of motion of the patient, normalizing the motor effort required to the skill set of the patient (Vourvopoulos, Faria, Cameirão, & Bermúdez i Badia, 2013).

Figure 2. *Interaction with the Reh@Task through the AnTS tracking software.*

This gamified VR task has a total of 120 difficulty levels, defined through a participatory design study, where the input of 20 health professionals was operationalized in quantitative guidelines (Faria & Bermúdez i Badia, 2015). The difficulty of the stimulus progression (Equation 1) was obtained through the manipulation of the variables: number of targets, number of distractors, and type of stimulus:

$$Difficulty = 3.610 + N_{targets}*0.12+N_{distractors}*0.15+Stimulus_{type} \qquad (1)$$

where $N_{targets}$ is the number of target elements, $N_{distractors}$ the number of distractors, and $Stimulus_{type}$ can take the following values: −0.494 for *numbers,* −1.054 for *letters,* and 0 for *symbols,* meaning that letters are easier than numbers and numbers easier than abstract symbols. The progression of the number of targets and distractors, the time available to solve the task, the duration of the selection timer and, in the memory variant of the task, the amount of time for memorizing the target was operationalized according to Figure 3. In summary, for higher difficulty levels, more target and distractor elements appear, less time is available for completing the task and memorizing the target images, and action selection is quicker. When a patient does not solve a specific level in the established timing, more time is given for that level. This additional time can be incremented up to three times. If the patient fails three times in a row, he goes back to the previous level. If the patient succeeds, the level must then be successfully performed within the original established time.

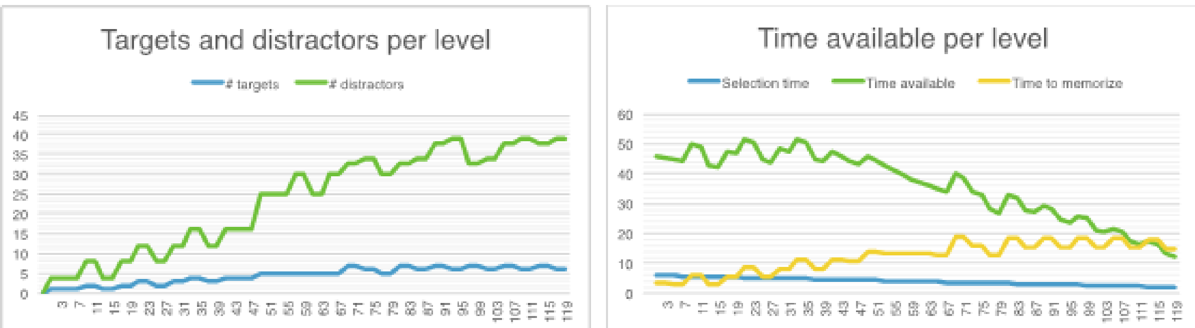

Figure 3. *Progression of the parameters of Reh@Task for the 120 different difficulty levels, including number of target elements, distractor elements as well as time related variables. See text for further information.*

Proc. 11th Intl Conf. Disability, Virtual Reality & Associated Technologies
Los Angeles, California, USA, 20–22 Sept. 2016
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In addition, a rule was defined to select the starting level in each training session as in Equation 2:

$$StartLevel_t = StartLevel_{t-1} + (EndLevel_{t-1} - StartLevel_{t-1})/2 \quad (2)$$

where *StartLevel* and *EndLevel* denote the starting and finishing levels respectively, and t indicates the session number. For instance, if the level achieved by a participant in the first session was 28, the second session would start in level 14 (28/2). If in the second session level 44 would be reached, the third session would start in level 29 (14 + (44-14)/2), and so on for the following levels.

2.3 Protocol

After recruitment, the twelve participants were assessed by an occupational therapist to obtain baseline measures for motor and cognitive domains. After the assessment, participants were randomly assigned to one of the groups by a researcher not involved in the data collection, using the Research Randomizer, a free web-based service that offers instant random sampling and random assignment (Research Randomizer, 2016). The assessor was not blind for the type of intervention. In addition to conventional occupational therapy, the experimental group went through twelve sessions of 45 minutes with the Reh@Task, three times a week, during one month. The control group intervention was time-matched, including conventional occupational therapy, spatial and time orientation activities and writing training. In the experimental group, before starting the twelve-session intervention, participants went through an average of three training trials with TP abstract stimuli. The training was intended to provide a clear understanding of the VR task, as well as to become used to the natural user interface (AnTS). After assuring that the patient understood the task and interface instructions, the intervention started with the attention variant of the task, then switched to memory, and so on intermittently. The progression of levels in the attention and memory tasks is independent, and a participant may, for instance, reach level 30 in attention and stay at level 25 in memory. At the end of the intervention and at follow up, all participants were assessed with the same assessment measures. The adherence to therapy rate was of 100% for all patients.

2.4 Cognitive, Motor and Functional Assessment

A number of cognitive and motor scales that are widely applied clinically and in research were used to determine impairment severity and to measure cognitive and motor recovery. The cognitive profiling was made through the Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2003), which provides sub scores for the following domains: Executive Functions, Naming, Attention, Language, Reasoning, Memory and Orientation. The attention task-related capabilities were assessed with the Single Letter Cancellation (Diller et al., 1974), the Digit Cancellation (Mohs et al., 1997) and the Bells Test (Gauthier, Dehaut, & Joanette, 1989). The upper-extremity deficits were measured through the Fugl-Meyer (Fugl-Meyer, Jääskö, Leyman, Olsson, & Steglind, 1975) Upper-Extremities components (Sullivan et al., 2011) and the Chedoke Arm and Hand Activity Inventory (Barreca et al., 2004). Spasticity was assessed through the Modified Ashworth Scale (Bohannon & Smith, 1987). Finally, to assess independence in the activities of daily living (ADL's), we used the Barthel Index (Mahoney & Barthel, 1965).

2.5 Data analysis

Data were analyzed using the Statistical Package for the Social Sciences 20. Because most distributions deviated from normality, non-parametric statistical tests were used. A Mann-Whitney test was done to assess differences between groups at baseline. Comparisons were performed between baseline, post-intervention and follow-up. For assessing change over time, a Friedman test was used. For within-subjects pairwise comparisons, the Wilcoxon's T matched pairs signed ranks test was used.

3. RESULTS

3.1 How effective is cognitive training with Reh@Task as compared to conventional rehabilitation?

We observed that both experimental and control groups had improvements, from baseline to post-intervention and follow-up, in the cognitive screening assessment score and in the performance of most cancellation tests (Table 2).

Table 2. *Montreal Cognitive Assessment (MoCA), Digit Cancellation (DC), Single Letter Cancellation (SLC) and Bells Test (BT) scores at baseline, post-intervention and follow up.*

		Experimental			Control		
		Baseline	Post-intervention	Follow-up	Baseline	Post-intervention	Follow-up
MoCA		22.50 (18-23.75)	26 (23.5-27.25)*	26 (21.5-28.5)*	21.5 (16-23.25)	24 (22.75-25.75)*	24.5 (24-25.25)*
DC	Time	5 (4-6.25)	4 (3-4)*	4 (4-5.25)	6 (5-6.5)	5.5 (4.75-7.25)	5.5 (4-7)
	Errors	1 (0-3)	.50 (0-1)	0 (0-1.5)	2 (1.75-2.25)	0 (0-.75)	1 (0-1)
SLC	Time	6 (4-13)	6.50 (4.75-7.75)	7 (4.75-12)	7.5 (6-8.5)	8 (6.5-9.75)	8.5 (7-11.25)
	Errors	2 (0-3.25)	1.50 (1-7.75)	3 (.75-5.25)	3.5 (3-10.25)	2.5 (2-9)	3.5 (2-4.75)
BT	Time	8.50 (5-10.75)	6 (4.75)	6.5 (5-9.5)	11 (9.75-12)	9.5 (8.75-11.75)	10 (10-11.25)
	Errors	4.50 (2.75-8.75)	3 (1.75-3.5)*	1.5 (1-3.25)	4.50 (4-5.25)	2 (2-4)	4 (2.75-5)

Values are presented as medians (quartile 1 – quartile 3).

* Wilcoxon's T matched pairs signed ranks test significance p <.05.

Changes over time in the MoCA scores, assessed with the Friedman's test, are significant in both experimental ($\chi^2(2)=9.478$, p=.009) and control ($\chi^2(2)=9.238$, p=.010) groups. A comparison showed higher average improvements in the group that used the Reh@Task, although not statistically different from control. The Wilcoxon's test revealed significant differences between baseline and post-intervention (Experimental: $W_{(6)}=21.000$, Z=-2.207, p=.027; Control: $W_{(6)}=15.000$, Z=-2.032, p=.042), and baseline and follow-up (Experimental: $W_{(6)}=21.000$, Z=-2.220, p=.026; Control: $W_{(6)}=21.000$, Z=-2.207, p=.027). In the analysis of MoCA subdomains, we found significant improvements for memory only in the experimental group ($\chi^2(2)=6.778$, p=.034), being that these changes are only significant from baseline to post-intervention ($W_{(6)}=15.000$, Z=-2.032, p=.042). Only the experimental group obtained significant improvements over time in the attention domain, as assessed with a reduction of time in the Digit Cancellation test ($\chi^2(2)=9.333$, p=.009) and a reduction of errors in the Bells test ($\chi^2(2)=7.182$, p=.028). However, according to the Wilcoxon's test, these differences are again only significant from baseline to post-intervention in both Digit Cancellation ($W_{(6)}=.000$, Z=-2.060, p=.039) and Bells ($W_{(6)}=.000$, Z=-2.032, p=.042) tests.

3.2 How effective is motor training with Reh@Task as compared to conventional rehabilitation?

Both groups improved quantitatively from baseline to post-intervention and follow-up in all the motor and functional assessment instruments (Table 3).

Table 3. *Fugl-Meyer (FM), Motricity Index (MI), Modified Ashworth Scale (AS), Barthel Index (BI) and Chedoke Arm and Hand Activity Inventory (CAHAI) scores at baseline, post-intervention and follow up.*

	Experimental			Control		
	Baseline	Post-intervention	Follow-up	Baseline	Post-intervention	Follow-up
FM	23 (17.50-52.25)	30.5 (22.25-52.25)	30.5 (22.25-53)	45.5 (43-50.5)	49.5 (44.5-52.75)	49.5 (45-63.75)*
MI	35 (30-77)	48 (36.5-77)	54.5 (39-79)	61 (56-69.75)	67 (59.75-78.75)	70 (65.5-78.75)*
AS	2.5 (1.88-3)	2 (1.38-3)	2 (1-3)	1.5 (1.38-2)	1.5 (1.38-1.5)	1 (1-1.5)*
BI	90 (63.75-96.25)	92.50 (63.75-100)	92.5 (65-100)	92.5 (51.25-100)	92.5 (51.25-100)	92.5 (51.25-100)
CAHAI	37 (30.25-74.5)	37 (34.25-75.25)	37 (34.25-75.25)	54.50 (42.75-61.25)	58.5 (48.25-66.25)*	62.5 (53.25-68.5)*

Values are presented as medians (quartile 1 – quartile 3).

* Wilcoxon's T matched pairs signed ranks test significance p <.05.

Considering the CAHAI functional assessment of the recovery of the arm and hand after stroke, we observe significant improvements over time in both experimental ($\chi^2(2)=6.000$, p=.050) and control ($\chi^2(2)=11.273$, p=.004) groups. Wilcoxon's pairwise comparison reveals that these differences are significant from baseline to post-intervention ($W_{(6)}=21.000$, Z=-2.226, p=.026) and to follow-up ($W_{(6)}=21.000$, Z=-2.207, p=.027) for the control group, but not for the experimental group. Only the control group had significant over time changes in upper-limb impairments, as assessed with the Fugl-Meyer ($\chi^2(2)=8.375$, $p=.015$), the Motricity Index ($\chi^2(2)=8.000$, $p=.018$) and the Modified Ashworth Scale ($\chi^2(2)=7.600$, $p=.022$). Pairwise comparisons were only significant from baseline to follow-up (FM: $W_{(6)}=15.000$, $Z=-2.060$, $p=.039$; MI: $W_{(6)}=15.000$, $Z=-2.032$, $p=.042$; AS: $W_{(6)}=21.000$, $Z=-2.207$, $p=.027$). In the case of independence in ADL's, there were no significant changes in the Barthel score for any of the groups.

4. CONCLUSIONS

Here we presented a VR cognitive and motor training task and the preliminary results of twelve patients from an ongoing one-month longitudinal intervention. During the experiment, all 12 patients underwent conventional occupational therapy rehabilitation, which mostly involves motor training and disregards cognitive aspects, but only the experimental group had specific attention and memory training with the Reh@Task. Experimental and conventional rehabilitation groups revealed improvements in the MoCA scores, although our data reveals that only Reh@Task participants improved significantly in the domains specifically trained by the VR task: attention and memory. The control group, despite improving in overall MoCA scores, did not present any specific improvements in any subdomain.

With respect to the motor component, both groups improved significantly in the functional recovery of the hand and arm scores assessed by the CAHAI, revealing that both the Reh@Task and conventional methodologies had an impact in the use of the hand and arm in the ADL's. Nevertheless, overall, the control group showed higher improvements. Improvements measured in Fugl-Meyer and CAHAI did not translate to an increased independence in ADL's, as assessed by the Barthel Index. This result may be explained by the fact that the Barthel Index is known to suffer ceiling effects (Quinn, Langhorne, & Stott, 2011). Improvements in the Fugl-Meyer, the Motricity Index and the Modified Ashworth Scale scores were only measurable in the control group. This might be due to the fact that the control intervention targeted a more generalized motor rehabilitation (occupational therapy based), whereas the Reh@Task system only targeted reaching movements of the hemi paretic arm.

To summarize, this work is part of an ongoing study that intends to include 40 participants, 20 per group. Despite the small sample size so far, our data suggests that both interventions have a positive impact in both motor and cognitive domains. In the cognitive domain, Reh@Task may have more impact in cognition, namely in the domains it directly addressed, memory and attention. In the motor domain, greater improvements are seen in the control condition. As a consequence of the reduced size of the sample, we have heterogeneous groups, with some differences between them concerning age, number of months post-stroke, as well as the Fugl-Meyer and Motricity Index scores at baseline. Although these differences are important and may have an impact in the results, they are not statistically significant. The increase of the sample size is expected to diminish these differences between groups and its impact in the final results.

These preliminary results are supportive of the viability of low-cost rehabilitation solutions that combine motor and cognitive training, such as the Reh@Task, that can be effective tools to address cognitive training in an integrative manner and can be easily deployed at home or at the clinic. Evidence that treatment effectiveness may improve by integrating cognitive and motor rehabilitation is increasing but more research is needed to identify how severity of deficits, chronicity and intervention delivery impact this association. Further research in this area is essential in order to provide more targeted interventions.

Trial registration: This trial was not registered because it is a small sample study that evaluates the clinical validity of a prototype virtual reality system.

Acknowledgements: This work is supported by the European Commission through the RehabNet project – Neuroscience Based Interactive Systems for Motor Rehabilitation – EC (303891 RehabNet FP7-PEOPLE-2011-CIG), and by the Fundação para a Ciência e Tecnologia through SFRH/BD/97117/2013 Projeto Estratégico – LA 9-2015-2016 and Agência Regional para o Desenvolvimento da Investigação, Tecnologia e Inovação (ARDITI).

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Longitudinal study of integrative virtual rehabilitation use in skilled nursing facility maintenance programs for residents with chronic stroke

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ABSTRACT

The objective of this 45-week longitudinal controlled study was to examine the effects of integrative virtual rehabilitation with BrightArm Duo System for the maintenance of skilled nursing facility programs for elderly residents with chronic stroke. The experimental group trained intensely for 8 weeks followed by 3 booster periods at 8-week intervals. The sessions were supervised by an occupational therapist. The control (n=3) and experimental (n=7) groups both received standard-of-care maintenance. The improvement for the experimental group was significantly better than the controls in standardized assessments of UE range of motion (p=0.04), strength, and function (p=0.035), and for cognition and emotion (p=0.0006).

1. INTRODUCTION

STROKE is the leading cause of disability in the US, with 795,000 Americans having a stroke each year (CDC, 2014). Although the mortality rate from stroke continues to decline (CDC, 2013), less than 15% of adults post-stroke recover complete upper extremity (UE) motor function (Hendricks, van Limbeek, Geurts, & Zwarts, 2002). Thus, millions of Americans in the chronic post-stroke phase (Rosamond et al., 2007) face a life of disability. Stroke affects quality of life, often causing depression (Sarah, 2009). The quality of life is even more diminished for the 15% of stroke survivors who become long-term resident of skilled nursing facilities (SNFs) (Jørgensen et al., 1995). Due to the aging of America, the societal costs associated with stroke are expected to grow to a staggering $240 billion *annually* by 2030 (Ovbiagele et al, 2013).

Health maintenance programs provided by Skilled Nursing Facilities (SNFs) are aimed at preserving arm function, flexibility, balance, and slowing down beyond age-related cognitive decline. However studies have not shown significant benefit to depression and self-esteem from participation in a SNF health maintenance program (Sung, 2007). Furthermore, such programs are not rehabilitation interventions, per se. They lack the number of task-oriented repetitions needed, strength training, as well as the appropriate length of training. This is especially problematic for long-term residents post-stroke who present with unique needs.

In the current managed care model, post-stroke therapy typically ends 6 to 9 months from a cerebrovascular accident. However, neuroscience has shown that UE function may continue to improve years post-stroke, as long as activities are task-oriented, repeated, and well attended (Jørgensen et al., 1995; Lamola et al, 2014). Given the limited nature of traditional therapy alternate options need to be explored that can deliver ongoing therapeutic benefit efficiently across a large number of participants through to the chronic post-stroke phase. Long-term residents of SNFs who survived a stroke present with a combination of motor, cognitive and emotive disabilities. They could benefit from therapy which addresses all these domains in an integrative way. This is unlike the current therapy model of separate, disjointed therapies by different clinicians: physical therapist, occupational therapists (OT), neuropsychologists, psychiatrists, speech language pathologists and others. By contrast, integrative rehabilitation addresses the motor, cognitive and emotive deficits in a single-point-of-care approach. Integrative virtual rehabilitation presented in this study, uses custom therapeutic games in which the participant is asked to solve cognitive problems (such as making decisions on object sequences or remembering the location of image pairs) through physical exertion (arm movement and grasping). The emotive domain is addressed by making the custom games always winnable and by lavishly congratulating for success. More importantly, as the difficulty level is adjusted in real-time, frustration is minimized and some success is enjoyed from every session.

In order to improve the current standard of care and meet the needs of SNF residents in the chronic phase post-stroke, Bright Cloud International Corp developed the BrightArm (Rabin et al., 2012) and subsequently the BrightArm Duo (Burdea et al., 2015; House et al., 2015, 2016). A longitudinal controlled study was started in the summer of 2014 to evaluate the BrightArm Duo use for maintenance therapy of elderly SNF residents who were in the chronic post-stroke phase of their condition. The results of the completed longitudinal study with comparisons between experimental and control groups are the focus of this paper.

2. METHODS

2.1 The BrightArm Duo rehabilitation system

As seen in Figure 1a), the BrightArm Duo Rehabilitation System is a robotic rehabilitation table with two computerized forearm supports and a therapist laptop that renders customs therapeutic games to an output display. The monitor was appropriately sized to provide a level of immersion without causing motion sickness in elderly population. The subject interacted with the virtual reality (VR) game environment through active arm movement and power grasp, both being tracked in real time. The serious game library was developed in Unity 3D (Unity, 2016) and provides upper extremity training either uni-manually or bimanually. Each session, the system automatically adapted to the subject’s forearm supported reach and grasp strength. Game difficulty, session duration, gravity loading on the upper extremity, were all gradated over the length of the training (House et al., 2015). The games mediated training for motor (shoulder, elbow, grasp), emotive (depression) and cognitive (executive function, focusing, short-term and delayed memory, working memory and task sequencing) training.

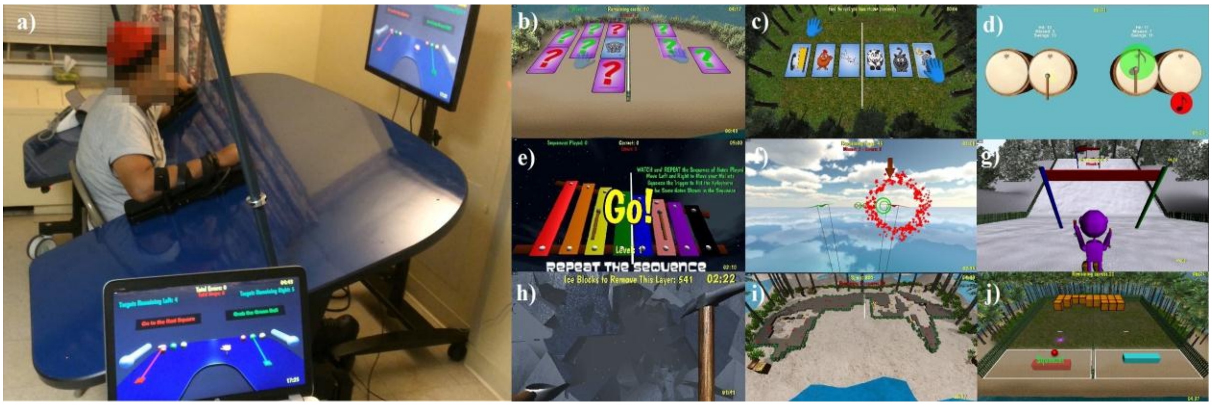

Figure 1. *a) BrightArm system with subject training bimanually on Pick & Place game. Additional games: b) Card Island; c) Remember that Card ; d) Musical Drums; e) Xylophone; f) Kites; g) Arm Slalom; h) Avalanche; i) Treasure Hunt; and j) Breakout 3D. © Bright Cloud International Corp. Reprinted with permission.*

Figure 1 also shows screen images of the ten games used in the study. In the game *a) Pick & Place*, the subject trained working memory by grasping a ball and moving it to a fixed target of matching color, using in-out or left-right arm movements. The matching card games *b) Card Island* and *c) Remember that Card* trained short-term and delayed visual and auditory memory, grasp strength, shoulder abduction/adduction, and shoulder flexion/extension. For *d) Musical Drums,* the subject trained focusing by controlling drum stick avatars to strike a series of notes that drifted across (up to four) drums. The *e) Xylophone* game trained short-term auditory and visual memory by having the subject repeat a sequence of musical notes using mallet avatars. The game *f) Kites* also trained focusing and motor control as the subject guided a pair of guides through a series of rings moving toward the front of the screen. Playing *g) Arm Slalom* induced shoulder rotations in order to guide a skier avatar through a downhill slalom course. In the *h) Avalanche* game, the subject cleared a series of ice walls using a pick axe and a shovel avatars through grasp and arm movements. In *i) Treasure Hunt*, the subject used one or two shovel avatars to clear sand and uncover a series of buried treasures. In the game *j) Breakout 3D*, the subject bounced a virtual ball toward an array of crates using paddle avatars. The game trained shoulder abduction/adduction or flexion/extension depending on crates orientation, as well as focusing and executive function.

2.2 Subject Characteristics

The study inclusion criteria were age 60 or older; a diagnosis of stroke that occurred at least 12 months prior to participation; English speakers; cognitive skills to actively participate; cognitive impairments in at least one of the domains of attention/concentration, speed of processing, memory, and/or executive functioning; clear motor involvement with the upper extremity (Fugl-Meyer Assessment score of 5 to 45); some ability to actively move the upper extremity (~15^o of total active range or better for shoulder and elbow flexion/extension). Patients were not enrolled until 4 months after casting procedures or Botox injections. Potential subjects were excluded from the study if they had severe visual neglect or were legally blind; or they presented with severe hearing loss; with receptive aphasia; with uncontrolled hypertension (>190/100 mmHg), with severe cognitive delay; non-English speakers; those with a history of violence. Potential subjects who were uncooperative with neuropsychological and motor/functional evaluations or could not comprehend the evaluation test instructions were excluded.

While approximately 100 potentials subjects were screened at the two participating SNFs, only 13 subjects met the inclusion criteria and were enrolled. Most individuals were excluded on the basis of no arm impairment on either side, or full arm impairment (flaccid) on one side. To improve the statistical reliability of experimental results, participants were divided 2-to-1 between the experimental group and the control group, in accordance to the approved protocol. Of these 2 subjects were lost to follow up and 1 subject was dropped from the study as being uncooperative with the investigators. The characteristics of the 10 subjects who completed the study are shown in Table 1. The subjects were able to converse in English, most of them were wheelchair bound and were comparable in terms of characteristics such as age, gender, and time post stroke.

Table 1. *Subject statistics and medical history pre-intervention for experimental (n=7) and control (n=3) groups of SNF residents chronic post-stroke. © Bright Cloud International Corp. Reprinted by permission*

Variable	Experiment (n=7)	Control Group (n=3)
Average Age	69.7 (13.3) years	70.1 (16.4) years
Gender	5 Male, 2 Female	2 Male, 1 Female
Race	4 White, 2 Hispanic, 1 Afr. Am	2 Afr. Am, 1 Hispanic
Primary Language	4 English, 2 Spanish, 1 French	3 English
Formal education	11.7 (3.8) years	10.7 (1.5) years
Time since stroke	98 (42) months	100 (28) months
Affected side	4 Left, 3 Right	1 Left, 2 Right
UE Function Impairment	3 Severe, 4 Moderate	1 Severe, 2 Moderate
Depression Level	6 Minimal, 1 Moderate	3 Minimal
Ambulation	6 Wheelchair bound, 1 Independent	2 Wheelchair bound, 1 bed bound
Co-morbidities	Diabetes Mellitus (4), Heart condition (4), Hypertension (3), Anaemia (2)	Diabetes Mellitus (2), Hypertension (2)

2.3 VR Maintenance Program

The VR maintenance program for the experimental group (Table 2) began with 8 weeks of intensive training, twice a week. Each rehabilitation session on the BrightArm Duo was supervised by an OT and assisted by a system technician. Participants' blood pressure and pulse were measured before and after each session. The OT also made sure the arms were positioned properly on the forearm supports. The participant's initial preparation was followed by baseline measurements of supported reach and grasp strength of the arm(s) being exercised in that session. Each session the experimental group played a sequence of up to 10 games in a set order and repeated as needed to achieve the specified session duration. The duration of actual game play increased from 20 minutes to 50 minutes per session. Gravity loading on the UE was increased by gradating the BrightArm Duo table tilt angle from 0° (horizontal) to a 20° upward tilt and adding wrist weights (up to 2 lb.) on each arm. Exercise difficulty was increased by migrating from easier games with no grasping to more difficult ones requiring sustained grasping.

The maintenance program continued with three booster cycles comprised of 10 weeks rest followed by two-week training (two sessions per week). The intent of the booster sessions was to maintain gains obtained in the initial 8-week intensive training. This is similar to the training of athletes who need to continue their training to remain in shape. The first two boosters followed a similar protocol to that used during the later sessions of initial intensive training. The final two booster weeks were a tournament, where each participant at one SNF played with another participant that was remotely located at the other SNF. The Western Institutional Review Board, an independent board overseeing research involving human subjects, reviewed and approved the protocol of this study in accordance with Federal Guidelines. The experimental training took place at Roosevelt Care Center, and at Hartwyck at Edison Estates, two SNFs located 8 miles apart in Edison, NJ, in 2014-15.

Table 2. *VR Maintenance program and assessments. © Bright Cloud International Corp. Reprinted by permission*

Maintenance Program	Activity	Assessments
Intensive Training	Train 8 weeks (2x/week)	A0 (Pre-training) & A1 (Post-training)
Booster 1	Rest 10 weeks, Train 2 weeks (2x/week)	A2 (Pre training) & A3 (Post-training)
Booster 2	Rest 10 weeks, Train 2 weeks (2x/week)	A4 (Pre-training) & A5 (Post-training)
Tournament	Rest 10 weeks, Train 2 weeks (2x/week)	A6 (Pre-training) & A7 (Post-training)

2.4 Data Collection Instruments

The purpose of the study was to demonstrate the benefit of a VR maintenance program supplement to current maintenance programs. Consequently, both experimental and control groups received the standard of care from their SNF's, but only the experimental group received added therapy on the BrightArm Duo system. The system generated data for each experimental therapy session (sessions 1 to 28). These included supported arm reach baseline, power grasp strength baseline, the number of active movements, the number of grasp repetitions, and game performance data (score, errors, completion time). Also, the experimental group subjectively evaluated the system after each training period in Table 2 (A1, A3, A5 and A7) by answering question survey using a 5 point Likert Scale (1=strongly disagree, 2=disagree, 3=neither agree or disagree, 4=agree, 5=strongly agree).

Standardized assessments of motor function were performed a maximum of eight times in Table 2. OT evaluations were performed by a Senior OT consultant who was blinded to the training protocol. These OT evaluations involved assessment of upper extremity function using the Fugl-Meyer Assessment – Upper Extremity Section (FMA) (Duncan, Propst, & Nelson, 1983), the Chedokee Arm and Hand Inventory – 9 (CAHAI-9) (S. Barreca et al., 2004) for bimanual tasks. The subjects completed the standardize Upper Extremity Functional Index (UEFI-20) Questionnaire at the start and end of the therapy (Chesworth et al 2014). Arm and hand range of motion were measured using mechanical goniometers, shoulder strength was assessed using wrist weights, grasp strength was measured with a Jamar mechanical dynamometer and a Jamar pinch meter.

Standardized emotive and cognitive assessments were performed up to 5 times (A0, A1, A3, A5, and A7). Neuropsychological evaluations were conducted by a research assistant (blinded to the therapy protocol) under the supervision of a licensed clinical neuropsychologist (JH who is also an author of this paper). These assessments included the Beck Depression Inventory, Second Edition (BDI-II) (Beck, Steer, & Brown, 1996) the Neuropsychological Assessment Battery (NAB) Attention Module (Orientation, Digit Span and Dots) and Executive Functioning Module (Generation subtest) (White & Stern, 2003),the Hopkins Verbal Learning Test, Revised (HVLT-R) (Brandt & Benedict, 2001), the Brief Visuospatial Memory Test, Revised (BVMT-R) (Benedict, 1997), and the Trail Making Test A and B (TMT) (Reitan, 1958). Alternate test forms were used whenever possible to minimize practice effect. Raw scores were utilized in all data analysis. Linear regression and paired t-test was used to measure associations across individual variables. Binomial sign test was used to evaluate trends across multiple metrics. A p-value < 0.05 was deemed statistically significant.

3. RESULTS

3.1 Training Intensity

The experimental group played on average total of 407 games lasting an average of 986 minutes over the 45 week study. These subjects exerted an average total of 19,020 arm repetitions and an average total of 12,540 hand grasps across the 45-week study. 9,370 arm repetitions and 5,990 hand grasps occurred during the initial 8 weeks of intensive training and the remaining 9,650 arm repetitions and 6,550 hand gasps occurred during the two booster and tournament periods. The baseline areas for the affected arm supported reach was on average of 187 cm^2 (S.D. 186 cm^2) at the beginning of the study and increased 75% to an average of 328 cm^2 (S.D. 217

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cm²) by the end of the study (p=0.05). The baseline for the unaffected arm supported reach started at 584 cm² (S. D. 316 cm²) and increased 70% to an average of 991 cm² (S. D. 449 cm²) by the end of the study (p=0.15).

Figure 2a illustrates the total arm repetitions per minute for the affected and unaffected arms. Sessions 1 to 16 correspond to the initial training period, sessions 17 to 20 and 21 to 24 were part of booster periods 1 and 2, while sessions 25 to 28 were part of the tournament. The training clearly became more intense with subsequent sessions, increasing along a slope of 6.6 repetitions per minute for the affected arm between sessions 1 and 28 ($p<0.001$). The slope was 5.7 repetitions per minute for the unaffected arm ($p<0.001$) between sessions 5 and 24 (the unaffected arm was not used in the last 4 sessions which was part of the tournament).

Figure 2b graphs the average game score for the experimental group by session number. The game score increased from 26 in session 1 to a high score of 66 in session 16, before leveling off to 61 during the booster and tournament periods. The linear fit has an intercept of 39.0 points at session 1 and increased along a slope of 1.1 points per session ($p<0.001$). The standard deviation of the game score increased over the initial training and the first two booster sessions, showing uniformity in performance decreases as game difficulty increases. The last 4 sessions on the graph depict tournament sessions and have smaller standard deviation compared to the previous booster sessions. This is due to the fact that the tournament was played uni-manually with the affected arm, such that a team of two subjects played a given game. This reduced the difficulty level for each subject, thus they performed more uniformly.

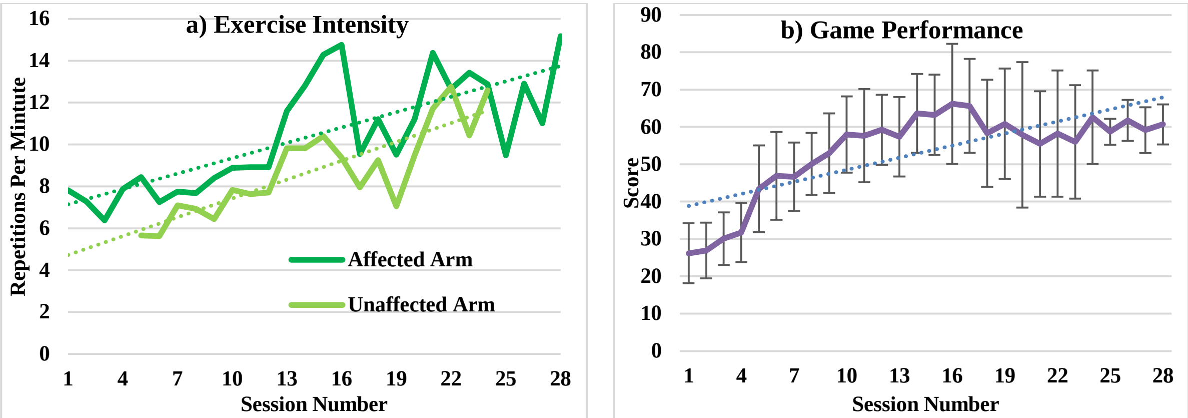

Figure 2. *a) Arm repetition intensity and b) composite game score and standard deviation by session number for the experimental group of Skilled Nursing Facility residents chronic post-stroke. © Bright Cloud International Corp. Reprinted by permission.*

3.2 Upper extremity active range of motion

As seen in Table 3, 19 out of 25 range of motion metrics for the experimental group improved between the assessments A0 and A7. The resulting binomial sign test was statistically significant (p=0.01). In comparison to the control group, the experimental group had better improvement for 18 of 25 range of motion metrics between assessments A0 and A7. The binomial sign test rejected the null hypothesis of no difference in the improvement between experimental and control groups (p=0.04).

3.3 Upper extremity functional assessments

Functional standardized measures also improved at post-tournament (A7) relative to pre-training (A0). Fugl-Meyer Assessment scores for the experimental group went up an average of 4 points from 15.6 to 19.6. The t-test results were statistically significant (p=0.03). FMA for the control group declined on average 5.0 points from 27.7 and to 22.7, near the minimal detectable change of 5.2 points (Wagner et al, 2008). CAHAI-9 increased from 11.9 to 22.9 for experimental subjects and the associated t-test was statistically significant (p=0.004). The 11 points improvement is higher than the minimal clinically important difference (MCID) of 6.3 points (Barreca, 2015), and is indicative of improved ability to perform bimanual Activities of Daily Living (ADLs). CAHAI-9 for control subjects declined 4.0 points from 30.0 to 26.0. UEFI-20 declined 3.7 points for experimental (34.5 to 31.4) and declined 6.3 points for controls (37.0 to 30.7). Neither met the MCID of 8 points (Chesworth et al., 2014).

3.4 Upper extremity strength

As shown in Table 4, 8 of 10 UE strength measures had larger improvement for the experimental group than the control group between assessments A0 and A7, but the sign test was not statistically significant (p=0.1).

Table 3 *Shoulder, elbow and finger range of motion (degrees) for experiment vs. control group of Skilled Nursing Facilities residents chronic post-stroke, with A0 pre-training and A7 post-tournament (week 45). * indicates sign reversed so all positive differences in table indicates improvement; <u>Underline</u> denotes A7-A0 better for experiment than control group. © Bright Cloud International Corp. Reprinted by permission.*

	Affected Arm						**Unaffected Arm**					
	Experimental n=7			**Control n=3**			**Experimental n=7**			**Control n=3**		
Variable	**A0**	**A7**	**A7-A0**	**A0**	**A7**	**A7-A0**	**A0**	**A7**	**A7-A0**	**A0**	**A7**	**A7-A0**
Shoulder Range of Motion												
Flexion	42.4	42.4	0.0	64.3	60.3	<u>– 4.0</u>	141.0	131.3	– 9.7	106	119	+13.3
Extension	18.7	44.0	+25.3	20.0	38.0	<u>+18.0</u>	65.6	69.9	+ 4.3	51.3	66.0	+14.7
Abduction	68.0	74.1	+ 6.1	78.3	77.0	<u>– 1.3</u>	151.6	144.4	– 7.1	129	135	+ 6.0
Adduction	6.3	7.4	+ 1.1	5.0	3.3	<u>– 1.7</u>	34.6	36.9	+ 2.3	27.7	29.3	<u>+ 1.7</u>
Internal rot	49.3	38.3	–11.0	64.0	42.0	<u>–22.0</u>	49.3	51.7	+ 7.3	34.0	43.3	+ 9.3
External rot	12.1	9.0	–3.1	20.0	0.0	<u>–20.0</u>	59.8	73.4	+13.8	64.0	75.0	<u>+11.0</u>
Elbow Range of Motion												
Flexion	130	132	+ 4.9	132	138	+ 5.7	144.6	148.6	+ 4.0	144	149	<u>+ 4.7</u>
*Extension	68.7	65.6	+3.1*	25.7	45.3	<u>-19.7*</u>	3.6	3.7	– 0.1*	0.0	0.0	<u>0.0</u>
Pronation	40.0	72.3	+32.3	90.0	93.3	<u>+ 3.3</u>	82.6	94.0	+11.4	86.0	89.3	<u>+ 3.3</u>
Supination	17.9	21.9	+ 4.0	41.0	58.7	+17.7	72.0	74.9	+ 2.9	51.0	73.3	+22.3
Finger Range of Motion												
Thumb	7.1	17.1	+10.6	36.7	20.7	<u>–16.0</u>	Within Normal Limits			Within Normal Limits		
Index	25.7	33.3	+ 7.9	53.3	47.7	<u>– 5.7</u>						
Middle	22.9	33.6	+10.7	34.3	30.0	<u>– 4.3</u>						
Ring	28.1	31.1	+ 4.7	43.3	19.0	<u>–24.3</u>						
Pinkie	27.9	37.4	+ 8.9	48.5	25.0	<u>–23.3</u>						

Table 4. *Hand and arm strength (Newton) for experimental vs. control group of chronic post-stroke residents in Skilled Nursing Facilities, with A0 pre-training and A7 post-tournament (week 45). <u>Underline</u> denotes A7-A0 better for experimental than control group. © Bright Cloud International Corp. Reprinted by permission.*

	Affected Arm						**Unaffected Arm**					
	Experimental n=7			**Control n=3**			**Experimental n=7**			**Control n=3**		
Variable	**A0**	**A7**	**A7-A0**	**A0**	**A7**	**A7-A0**	**A0**	**A7**	**A7-A0**	**A0**	**A7**	**A7-A0**
Ant. Deltoid	6.0	15.3	+ 9.2	5.2	13.3	<u>+ 8.1</u>	21.3	55.3	+ 34.9	22.2	38.6	<u>+ 16.3</u>
Lat. Deltoid	6.7	19.1	+12.4	5.9	13.3	<u>+ 7.4</u>	21.3	53.4	+ 32.1	22.2	38.6	<u>+ 16.3</u>
Hand Grip	7.6	25.4	+15.9	106	40.0	<u>– 66.1</u>	247	246	– 0.5	225	195	<u>– 30.4</u>
Tip Pinch	0.0	0.0	0.0	10.1	0.0	<u>– 10.1</u>	54.6	48.5	– 6.1	30.7	32.8	+ 4.7
Jaw Pinch	1.0	0.6	– 0.4	22.9	20.8	<u>– 2.1</u>	43.5	42.3	– 1.2	36.9	41.7	+ 2.1

3.5 Cognitive and emotive outcomes

Figure 3a shows that depression severity (as measured by BDI-II) for the experimental group dropped from 8.0 to 3.7 points between A0 and A7. The t-test was statistically significant (p=0.01) and the improvement approaches the MCID of 5 points (Hiroe et al., 2005) for this measure. By comparison, depression severity for the control group became worse, and increased 8.3 points from 2.7 to 11 points when measured with the BDI-II test.

HVLT-R was used to measure verbal learning and memory. Its scores increased 3.2 points from 15.1 (A0) to 18.3 (A7) for the experimental group, but decreased from 2.7 to 0.0 points for the control group (Figure 3b). BVMT-R was used to measure visuospatial memory. Its scores increased 4.0 points from 5.9 (A0) to 9.9 (A7) for the experimental group and decreased by 0.3 points from 1.0 to 0.7 points for the control group (see Figure 3b).

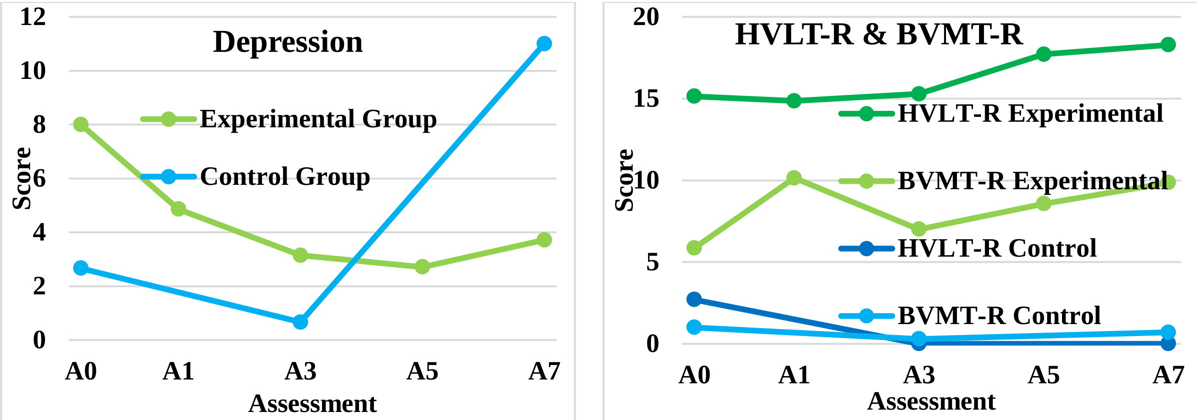

Figure 3. *a) BDI-II depression score and b) HVLT-R and BVMT-R scores for the experimental group (n=7) and control group (n=3) of chronic post-stroke residents in Skilled Nursing Facilities. Assessments intervals were pre- and post- initial training (A0 & A1), post-booster 1 (A3), post-booster 2 (A5) and post-tournament (A7). © Bright Cloud International Corp. Reprinted by permission.*

3.6 Subject Attendance to Protocol and Subjective Feedback

The experimental group attendance was 97% during the initial training and 100% during booster periods 1 and 2. Attendance dropped to 93% during the tournament as one subject decided to leave the study during the final week. Experimental group participants subjectively evaluated the system after each training period using a 5 point Likert Scale. The mean response was 3.7 out of 5 after the initial training (A1), 3.5 after the first booster (A3), 3.5 after the second booster (A5) and 3.8 after the tournament (A7). The mean score overall was 3.6 out of a max of 5 points. The two ratings below 3.0 were in response to the statements: ‘Playing games with affected arm was easy’ (score 2.7) and ‘Playing with both arms is easy’ (score 2.8). The ratings were 4.0 or better for the questions: ‘I would encourage others to use it’ (score 4.0); ‘The instructions were useful’ (score 4.1); and ‘I liked the system overall’ (score 4.2). The highest response was 4.7 in response to the statement: ‘Enjoyed playing with a partner’

4. DISCUSSION

The purpose of this study was to demonstrate the benefit of a VR maintenance program supplement to maintenance programs alone. Consequently, both experimental and control groups received the standard of care from their SNF’s, but only the experimental group received added BrightArm Duo VR training. Neither the control group nor the experimental group received intensive upper body exercising as part of their standard of care. Thus the measured difference in gains can only be attributed to the VR component.

In making the rehabilitation process more interactive, fun and engaging for the elderly participants, BrightArm Duo technology was able to gain their acceptance as shown in the positive results of the subjective reports and high attendance rate. As reported in a recent scoping review of serious balance training games, older adults generally consider the usability and acceptance of serious games good (Nawaz et al., 2015). BrightArm Duo system is unique in its offering of VR intense training along with specially designed games and controllers to adapt the system to the individual needs of the participant.

The results of this study are in line with those of a virtual reality control study of SNF residents (Optale et al., 2010). The researchers in that study found that the experimental group showed significant cognitive improvements while controls showed progressive decline (Optale et. al., 2010) . The study duration of the cognitive VR intervention was 6 months, as compared to the 10-month maintenance study described here. The current study targeted integrative training of UE function and impairments, cognition and emotive state in elderly chronic post-stroke. It is possible that a longer duration of intervention could have resulted in more benefits for the experimental group. However the objective of the present study was primarily to initially increase and then maintain function of these elderly residents. From this perspective the authors consider the study a success. The duration of training is an aspect that is not studied for longitudinal trials chronic post-stroke and needs further investigation.

This longitudinal study was able to examine the lasting effects of VR training on motor function, cognition and emotive state. The maintenance effects were enhanced by periodic short boosters and lasted well beyond the 8-week intense training. This might indicate brain plasticity effects triggered by VR training as reported in some of the recent literature. Villiger et al., (2015) used magnetic resonance imaging before and after a 4-week VR training in people with chronic spinal cord injury and reported structural changes in the brain induced by VR training. The current study did not involve brain imaging. By closely examining the brain, future longitudinal studies can contribute to understanding the science of virtual rehabilitation.

The current study does have limitations in the small sample size, lack of caregiver data, and lack of quality of life data to support the results. Recruitment difficulties at the two SNFs were due to residents having multiple co-morbidities, including many with complete lack of movement in their affected arm. The inclusion criteria which required that prospective subjects have some arm movement, coupled with the generally low function levels of the SNF residents made it difficult to achieve a larger sample size. This further supports the need for early and ongoing interventions to take advantage of increased neuroplasticity early after stroke, and then maintain gains. Future research with the BrightArm Rehabilitation System is needed to investigate the earlier stages post-stroke where larger magnitude of gains in impairment, motor function, cognitive level and reduced depression may be possible.

5. CONCLUSIONS

In summary, the experimental group trained on BrightArm Duo System performed on an average of 19,020 active arm repetitions and 12,540 hand grasps across the 45-week study. This resulted in statistically significant improvements in UE range of motion and strength on the affected and unaffected sides and functional improvements on ADL measures of uni-manual and bimanual function when compared to control group subjects. The decline in the control group may be attributed in part to the fact that these were elderly stroke survivors, as opposed to healthy age-matched controls. The experimental group also showed statistically significant improvements in cognition, particularly related to new memory encoding, maintenance and subsequent retrieval regardless of modality (verbal and visual). The statistically significant reduction in depression severity was notable at the end of the intensive training and was maintained through the longitudinal trial duration, compared to the control group who continued to decline.

To conclude, there are indications that integrative training with BrightArm Duo was effective in improving UE range of motion, strength, function, cognition, and in reducing depression with intense 8-week training. The effects were maintained at 45-week follow up with periodic short duration (2-week) boosters in the experimental group, while the control group continued to decline. Both groups received the standard maintenance programs of their respective SNF.

Acknowledgements: Research reported here was supported by grant 9R44AG044639-02A1 from the National Institute on Aging/NIH. We wish to thank Abby Eisner OT and Daniel Saldana who performed the clinical evaluations, as well as Pooja Joshi OT and Melissa Langewisch OT who trained the subjects.

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Competition improves attention and motivation after stroke

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ABSTRACT

Cognitive deficits are a common sequelae after stroke. Among them, attention impairments have the highest incidence and limit functional recovery and quality of life. Different strategies to improve attention have been presented through the years, even though its effectiveness is still unclear. Basing on the human competitive nature, competitive strategies have been proposed to increase motivation and intensity. However, this approach has been never applied to train attention after stroke. In this paper, we present a randomized controlled trial that evidences the important role of competition in cognitive functioning. Our results support that competitive strategies combining virtual reality-based and paper and pencil tasks can improve attention and motivation after stroke to a greater extent than non-competitive paper and pencil tasks.

1. INTRODUCTION

Cognitive impairments are among the most common sequelae after stroke, affecting to more than half of the cases (Hochstenbach et al., 1998). Among them, attention deficits present the highest incidence, with rates ranging from 46% to 92% of the cases in the acute phase (Hyndman et al., 2008). When compared to healthy controls, individuals post-stroke evidence slower reaction time and alerting deficits, which have been linked to dissociated attention networks (Rinne et al., 2013). Since attention is a basic cognitive skill that sustains higher cognitive processes, impaired attention can affect the general cognitive functioning even when other functions are intact (Lezak, 1995), thus limiting learning (Schmidt, 2011), social cognition (McDowd et al., 2003), and, in the end, functional recovery (Robertson et al., 1997) and quality of life (Nys et al., 2006). Importantly, attention deficits have been reported to be more incapacitating than motor impairments (Zhu et al., 1998).

Different interventions have been presented to improve attention after stroke (Cha et al., 2013). The customization of the rehabilitation programs, for example by adjusting both the intensity (Penner et al., 2012) and the difficulty of the tasks to each subject's condition (Brehmer et al., 2012), is essential to maximize the efficacy of the interventions. In the last decade, an increasing number of studies have reported the efficacy of computerized programs to improve different cognitive skills (Cha et al., 2013; Bogdanova et al., 2015).

Different factors have been reported to promote cognitive rehabilitation. First, audiovisual content, feedback on the performance, and cognitive challenges (Maclean et al., 2000) have been shown to increase the intensity and duration of the training while increasing the motivation (Novak et al., 2014). Second, social interaction through multiplayer strategies have been reported to improve not only motivation but also adherence to the treatment (Carignan et al., 2006). Actually, users have reported to prefer multiplayer to single-user interaction via either competitive or non-competitive exercises (Wittchen et al., 2013). However, there is no previous reports on the effects of competitive training on attention rehabilitation.

The objective of this study is threefold. First, to determine the efficacy of a competitive group intervention to improve attention deficits in chronic stroke survivors in comparison to a non-competitive group program. Second, to evaluate the motivation elicited by both interventions. Finally, to determine the usability of a virtual reality-based multiplayer competitive system used in the competitive intervention.

2. METHODS

2.1 Participants

Participants were recruited from the stroke outpatient management program of NISA Valencia al Mar Hospital (Valencia, Spain). The inclusion criteria for the current study were: 1) chronicity > six months; 2) slow processing speed, as defined by T-scores of the reaction time in the Conners' Continuous Performance Test 2nd Edition (CPT) (Homack et al., 2006) ≥ 60; 3) fairly good cognitive condition, as defined by scores on the Mini-Mental State Examination (Folstein et al., 1975) > 23; 4) inclusion in a cognitive rehabilitation program for more than 3 months. Participants were excluded if they had: 1) impaired comprehension that hindered sufficient understanding of the instructions, as defined by Mississippi Aphasia Screening Test (Romero et al., 2012) scores below 45; 2) severe visual impairments; 3) severe paresis of the upper limb that prevent interaction with the instrumentation, as defined by Upper Extremity subscale of the Fugl-Meyer Assessment (Sanford et al., 1993) < 19; 4) spatial neglect; and 5) emotional or behavioural circumstances that impeded adequate collaboration.

The study was approved by the Institutional Review Board of the NISA Valencia al Mar Hospital. All the subjects who satisfied the inclusion criteria and accepted to participate in the study provided written consent.

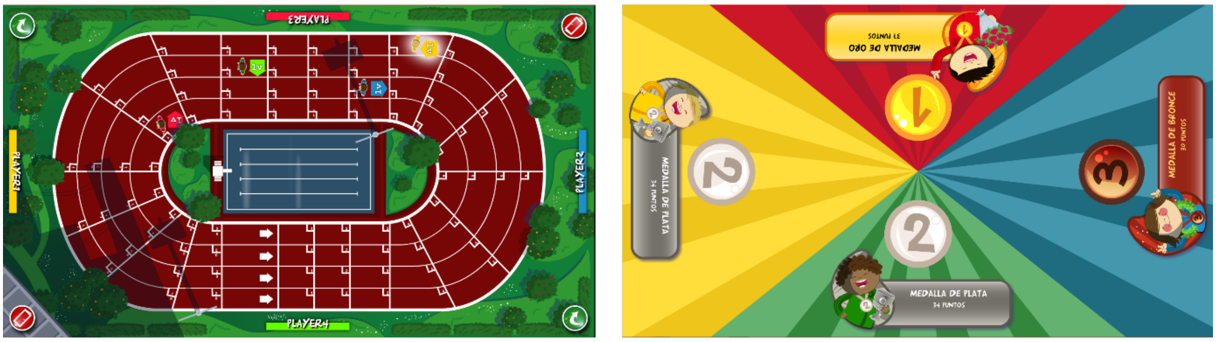
Participants were randomly assigned to an experimental or a control group. The allocation sequence was concealed from an independent researcher. A sealed envelope identifying the group of each participant was given to the therapists to inform them of the allocation. Randomization was computer-generated using a basic random number generator in a ratio of 1:1.

2.2 Instrumentation

2.2.1 Paper and pencil tasks. A battery of conventional paper and pencil tasks was designed to train different attentional skills. Exercises focused on alertness, reaction time, selective, divided, and sustained attention, while involving visual scanning, visual memory, and working memory. The results of the exercises provided information about correct and wrong answers, and reaction time.

2.2.2 Multiplayer virtual reality-based system. A multitouch table system with customized exercises was used during the intervention. The system consisted of a conventional 42″ LCD screen embedded in a conventional table and oriented in a horizontal plane (parallel to the floor) (Llorens et al., 2012; Llorens et al., 2013). The interactive capability was provided by a multitouch frame fixed over and along the screen frame that detected a maximum of 32 touches simultaneously. The system allowed different participants to sit in each side thus enabling group-based interventions with high reports of motivation and usability (Llorens et al., 2015). The system run on an Intel® Core™2 E7400 @2.8GHz with 3 GB of RAM and a NVIDIA® GeForce® 9800 GT video card with Windows 7. Visual and auditory feedback was provided using the TV speakers.

The multi-touch screen displayed the virtual environments, which were inspired in the Olympic Games. The main screen of the game displayed a running track from above with different avatars that represented the participants (Figure 1.a). Different races and male and female characters were available.



(a) *(b)*

Figure 1. *Snapshots of: a) the main screen; and b) the results screen after each exercise.*

The main objective of the game, as in track and field, was to move further away than the rest of the participants. To this end, participants had to compete in different exercises. Participants moved forward in the track according to their performance in the exercises. Specifically, the winner moved forward 4 steps, the runner-up moved forward 3 steps, and so on (Figure 1.b). In case of draw, the participants achieved the same score and consequently moved the same numbers of steps.

The system included eight exercises that focused on the same attentional skills that were involved in the paper and pencil tasks, mainly related to attention, and recreated different Olympic events and scenarios (Table 1, appended). Besides the cognitive demand of each exercise, the timing of the required actions was important. As a proof, in marathon and public, participants had to grab an item or to identify a character as fast as possible, respectively. In contrast, all the actions in cycling, tennis, duathlon, and triathlon had to be done at the precise moment, which was highlighted in the environment with changing colors (for instance, in cycling, when an obstacle entered in the area of interaction of the character, the area turned into green, thus indicating that the user should press the button to avoid the obstacles). This way, not only reaction was trained but also impulsiveness.

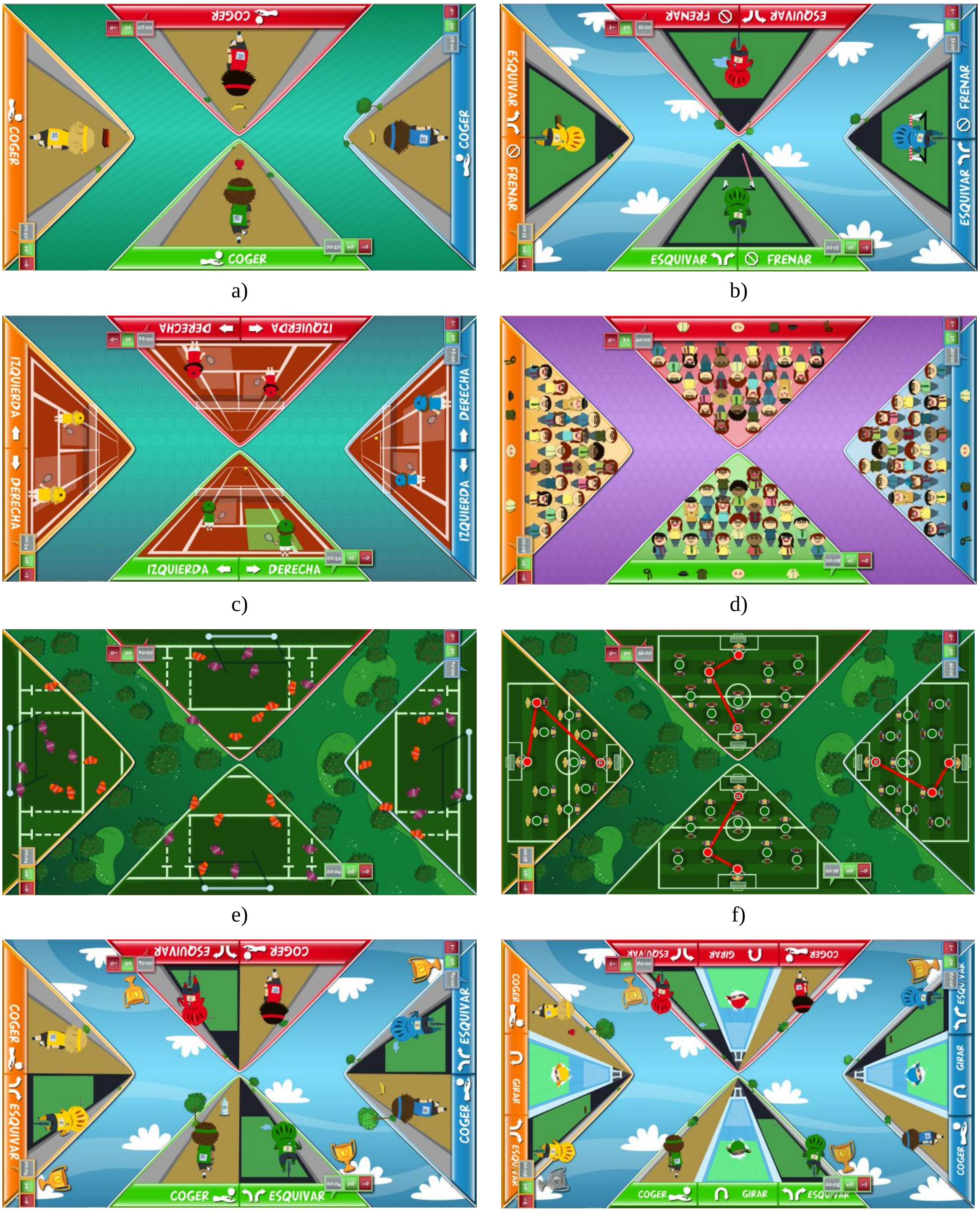


Figure 2. *Snapshots of the exercises: a) marathon; b) cycling; c) tennis; d) public; e) football; f) soccer; g) duathlon; and h) triathlon.*

Participants interacted with the game board by touching buttons or other items on the screen (Table 1). The level of difficulty was customizable by adjusting different parameters in each exercise (Table 1). During the exercises, the system provided feedback about the number of right and wrong answers, the remaining time, and the current position. At the end of them, a small closing ceremony with the medal awards was recreated to provide general feedback of the performance.

2.3 Procedure

All the participants underwent 30 one-hour group sessions of four participants administered 3 days a week. Number of sessions and dosage were, consequently, paired. Interventions, in contrast, differed between groups. Participants belonging to the control group trained using the battery of paper and pencil tasks described above. Participants belonging to the experimental group trained using competitive exercises, alternating sessions of paper and pencil tasks with sessions using the described multiplayer virtual reality-based system. In the control group, paper and pencil tasks were completed in group but independently. In the experimental group, the same tasks were completed competing to finish in first place, with the highest number of right answers, or with the lowest number of errors. Sessions with both paper and pencil tasks and the multiplayer system included 8 exercises that focused on the cognitive skills described previously in randomized order. The duration of each exercise, either paper and pencil or through the virtual reality-based system, was 6 minutes. Breaks of 1.5 minutes were allowed between them. All the sessions were conducted by an experienced therapist who gave feedback about the results after each exercise and specific instructions before each exercise (during the breaks). The difficulty of all the exercises was determined in an exploratory session according to participants' condition.

Participants were assessed before and after the intervention with a battery of clinical tests that evaluated visual scanning, reaction time, sustained attention, and inhibition, abilities that were mainly trained during the intervention. The assessment included the CPT, the d2 attention test (d2) (Bates et al., 2004), and the Part A of the Trail Making Test (TMT-A) (Reitan, 1958). The CPT is a computerized test that assesses multiple facets of attention, as reaction time, selective and sustained attention, and impulsivity. In the second edition of the test, clients are told to click the space bar as quick as possible when they are presented with any letter except the letter "X". Stimuli are presented at 1, 2, or 4 s intervals, thus defining different blocks, during 14 minutes. The d2 is a paper and pencil test that assesses visual scanning speed and selective and sustained attention. The test has 14 lines with series of similar letters surrounded by marks. Participants are required to cross out any letter "d" with two marks around above it or below it that are present in each line and discard distractors. Participants have 20 s to finish each line. The TMT-A is a paper and pencil task that evaluates visual search speed and scanning. The test consist of 25 numbered circles distributed over a sheet of paper. Participants are required to draw lines to connect the numbers in ascending order as quickly as possible.

Reaction time was assessed with the Hit Reaction Time score of the CPT (CPT-HitRT), the average speed of correct responses for the entire test, and the time to complete the part A of the TMT (TMT-A). Sustained attention was assessed with the total score of the d2 (d2-T), the Hit Reaction Time by Block (CPT-HitRT-BC), which measures change in reaction time across the duration of the test, and the Standard Error by Block (CPT-HitSE-BC), which detects changes in response consistency over the test. Inhibition was assessed by the Commisions score of the CPT (CPT-COM), i.e. the responses given to non-targets, and the Concentration Index of the d2 (d2-CON), which is the difference between number of right answers and commisions.

In addition to the clinical assessment, after the intervention, participants reported their motivation through four subscales of the Intrinsic Motivation Inventory (IMI) (McAuley et al., 1989). Participants belonging to the experimental group also assessed the usability of the system with the System Usability Scale (SUS) (Bullinger et al., 1991). The IMI is a multidimensional questionnaire structured into various subscales. Each subscale includes different questions rated on a seven-point Likert scale. In this study, this questionnaire was used to assess participant interest/enjoyment, perceived competence, pressure/tension, and value/usefulness measures. The SUS is a simple ten-item scale that serves as a global assessment of subjective usability. It employs a Likert scale with scores ranging from 0 to 100.

2.4 Data analysis

Demographical and clinical comparisons between the control and the experimental group were performed with independent sample t-tests and Chi-squared or Fisher exact tests, as appropriate. Repeated measures analyses of variance (ANOVA) with time as the within-subjects factor and treatment option (control versus experimental) as the between-subjects factor were performed for the clinical tests and the motivation quesionnaire. The main effects were evaluated for time, treatment option, and the time-treatment option interaction. ANOVA findings that violated the sphericity assumption were accommodated by Greenhouse and Geisser's conservative degrees of freedom adjustment. For each repeated-measures ANOVA, we present the partial eta squared ($\eta^2 p$) as a measure of effect size; values may range between 0 and 1, with higher values representing higher proportions of variance explained by the independent variable.

The α level was set at 0.05 for all analyses (two-sided). All analyses were computed with SPSS Statistics version 22 (IBM®, Armonk, NY, USA). Investigators performing the data analysis were blinded.

3. RESULTS

3.1 Participants

A total pool of 106 subjects were eligible candidates to participate in this study. Of those, 27 subjects (25.5%) met inclusion criteria. None of them refused to participate in the study, and consequently all of them were randomized. The experimental group consisted of 14 participants and the control group consisted of 13 participants. Two participants, one of each group, discontinued during the intervention due to discharge and worsening health. Consequently, these data were not considered for analysis. Data from 25 participants, 13 in the control group and 12 in the experimental group, were included in this study. The final sample consisted of 15 males and 10 females, with a mean age of 54.4±9.0 years, and a mean chronicity of 402.8±295.5 days. A total of 15 participants presented an ischemic stroke, and 10 participants presented a hemorrhagic stroke (Table 2). No significant differences in demographical (gender, age, and education) or clinical (etiology, localization, chronicity, and CPT-HitRT) data at inclusion were detected between the groups.

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

Characteristic	Control group	Experimental group	Significance
Sex (n,%)			
Male	9 (69.2 %)	6 (50.0 %)	NS (p=0.327)
Female	4 (30.8 %)	6 (50.0 %)	
Age (years)	54.3±8.8	54.5±9.6	NS (p=0.971)
Education	13.6±4.3	11.2±3.7	NS (p=0.139)
Chronicity (days)	289.2±98.4	266.4±78.4	NS (p=0.530)
Etiology (n,%)			
Hemorrhagic	4 (30.8 %)	6 (50.0 %)	NS (p=0.327)
Ischemic	9 (69.2 %)	6 (50.0 %)	
Localization (n,%)			
Right	6 (46.1%)	1 (8.3 %)	NS (p=0.202)
Left	5 (38.5%)	6 (50.0 %)	
Bilateral	0	2 (16.7 %)	
Cerebellar	1 (7.7 %)	2 (16.7 %)	
Brainstem	1 (7.7 %)	1 (8.3 %)	
CPT Hit reaction time (s)	471.9±99.4	488.7±131.3	NS (p=0.721)

3.2 Clinical measures

The analysis of the results revealed that both groups improved their reaction time, sustained attention, and inhibition (not in the CPT-COM) after the intervention (Table 3). With respect to the clinical measures throughout the therapy, post hoc analysis showed that participants improved in all the measures but in the CPT-HitRT-BC and the CPT-COM. When comparing the progression of both groups, participants belonging to the experimental group significantly improved in the CPT-HitRT and the TMT-A, both measuring reaction time, and in both indexes of the d2. The only worsening after the intervention was experienced by the experimental group in the CPT-COM.

3.3 Motivation and usability

Participants in the experimental group reported the competitive training to be significantly more enjoyable and useful than the non-competitive training, and reported that the multiplayer system used in the experimental intervention had high acceptance in terms of usability (Table 4).

Table 3. *Clinical data. Data are expressed in mean ± standard deviation when possible. T: time effect. GxT: group-by-time effect. NS: no significance. *: p<0.05. **: p<0.01.*

Measure	Initial assessment	Final assessment	Significance (p, effect size)
Reaction time			
CPT Hit Reaction Time (ms)			
Control	471.9±99.4	466.5±79.7	T* (p=0.019, η^2=0.22) GxT* (p=0.045, η^2=0.16)
Experimental	488.7±131.3	426.0±104.7	
Trail Making Test. Part A (s)			
Control	60.8±21.6	58.5±22.0	T** (p=0.004, η^2=0.31) GxT* (p=0.014, η^2=0.24)
Experimental	68.2±26.0	44.5±18.5	
Sustained attention			
d2 Total score (n)			
Control	289.8±72.2	291.9±57.1	T* (p=0.015, η^2=0.23) GxT* (p=0.018, η^2=0.22)
Experimental	249.0±112.9	386.1±178.8	
CPT Hit Reaction Time by Block (ms)			
Control	7.7±20.5	0.8±22.2	T** (p=0.003, η^2=0.32)
Experimental	24.2±17.3	13.3±10.7	
CPT Standard Error by Block (ms)			
Control	45.4±64.6	39.2±34.5	NS
Experimental	19.2±34.2	10.8±41.7	
Inhibition			
d2 Concentration Index (n)			
Control	105.8±36.5	106.5±24.4	T* (p=0.019, η^2=0.28) GxT* (p=0.045, η^2=0.27)
Experimental	73.1±56.0	151.0±93.3	
CPT Commisions (n)			
Control	10.0±5.2	9.8±5.5	NS
Experimental	9.0±7.8	12.2±5.9	

Table 4. *Motivation, enjoyment, and usability data. Data are expressed in mean ± standard deviation when possible. NS: no significance.*:p<0.05. **:p<0.01.*

Measure	Control group	Experimental group	Significance
Intrinsic Motivation Inventory			
Interest/enjoyment	5.2±1.0	6.1±0.8	p=0.030
Perceived competence	4.8±1.1	4.9±1.5	NS (p=0.873)
Pressure/tension	2.1±1.0	3.0±1.7	NS (p=0.111)
Value/usefulness	5.2±1.2	6.1±0.8	p=0.037
System Usability Scale	-	81.3±10.9	-

4. CONCLUSIONS

Although some previous studies have focused on restoring the attentional functions after stroke, none of them have used a competitive strategy (Cha et al., 2013). This study evaluates the efficacy of a competitive rehabilitation program to improve attention deficits after stroke in comparison to conventional non-competitive paper and pencil tasks. Our findings support the efficacy of both rehabilitation programs. Both, control and experimental interventions promoted significant benefits after treatment with regards to reaction time (CPT-HitRT, TMT-A), sustained attention (d2-T, CPT-HitRT-BC), and inhibition (d2-CON).

In addition, participants belonging to the experimental group showed greater benefits than healthy subjects in almost all these measures. Only one of the measures of sustained attention (CPT-HitRT-BC) did not show a group-by-time interaction, but even in this case, the competitive strategy provided higher improvement than the non-competitive training. The intrinsic motivation derived from the competitive approach could have led to a self-promoted more intensive intervention. Previous studies have consistently shown that virtual reality may be able to increase patient motivation during motor rehabilitation (Popovic et al., 2014). In addition, competition, when played in a controlled environment, may act as an extrinsic incentive to reinforce learning (Deci et al., 1999). It has been suggested that cognitive training of certain attentional domains might be more effective than others (Cappa et al., 2005), as is the case of divided attention (Cha et al., 2013). Interestingly, the use of computerized systems to improve attention has described benefits in a wider spectrum of attentional measures, specifically in processing speed, which supports our results, and in working memory (Bogdanova et al., 2015). However, previous reports comparing conventional and computerized intervention in attention programs are not conclusive (Barker-Collo et al., 2009; Bogdanova et al., 2015), and some authors argue that there is limited evidence of improvement in performance of specific attention tasks after computerized programs (Teasell et al., 2014). This could support that the improvement described in the experimental group is promoted by the competitive approach, beyond the multiplayer system.

The worsening in the inhibition described by the CPT-COM could be an effect of the improvement in the alertness and reaction time experienced along the intervention. This way, while participants could react before, it could have also led them to be more impulsive and increase the commissions.

With regards to the motivation, even though participants who competed experienced non-significant but higher levels of tension, this group assessed this intervention as being more enjoyable and useful than non-competitive training. In addition, participants who used the multiplayer system rated it as being highly usable, with scores clearly above the suggested cut-off of 70 that classifies systems as acceptable.

These results must be interpreted taken into account the limitations of the study. First, the sample size, even though it is similar to or even greater than that in other studies, can be considered small. Second, data of personal traits were not available, thus preventing the analysis of their implication in effectiveness and motivation of the training. Third, since participants were attending a rehabilitation program for three months, it is not possible to discern whether the improvement detected in both groups was promoted by the intervention or by the change of intervention itself. Finally, follow-up data, which could have depicted the maintenance of gains, is not available. Future studies should address these issues. However, the chronicity of the sample and the results evidence the positive effects of competitive strategies to train attention after stroke.

Acknowledgements: The authors wish to thank the staff and patients of the Hospital NISA Valencia al Mar for their involvement in the study. This study was funded in part by Ministerio de Economía y Competitividad (Project TEREHA, IDI-20110844 and Project NeuroVR, TIN2013-44741-R) Ministerio de Educación y Ciencia Spain, Projects Consolider-C (SEJ2006-14301/PSIC), “CIBER of Physiopathology of Obesity and Nutrition, an initiative of ISCIII” and the Excellence Research Program PROMETEO (Generalitat Valenciana. Conselleria de Educación, 2008-157).

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Table 1. *Description of the competitive exercises of the multiplayer system.*

Exercise	Skill	Environment	Interaction	Objective	Input parameters	Output parameters
Marathon	Sustained attention	A road with a running character. Different items appear above him/her (Figure 1.a)	One button: To grab	To grab water and fruits as fast as possible and avoid the brick	Speed	Correct answers, Omissions, Commissions
Cycling	Alertness and selective attention	A road with a cycling character. Different obstacles approach (Figure 1.b)	Two buttons: To turn To brake	To avoid puddles and logs in the road or stop at level crossing	Speed, Area of interaction	Correct answers, Omissions, Commissions
Tennis	Impulsiveness	A doubles game in a tennis court (Figure 1.c)	Two buttons: Left player Right player	To return the ball with the left or right player	Speed, Area of interaction, Time between ball shots	Correct answers, Omissions, Commissions
Public	Visual scanning	A grandstand full of fans (Figure 1.d)	Screen touches	To identify facial features in the crowd as fast as possible	Time to identify the features, Number of characters, Number of features	Correct answers, Omissions, Commissions
Football	Visual tracking	A football field with players of two teams (Figure 1.e)	Screen touches	To identify football players and a ball after a play	Number of players, Number of players to be tracked, Duration of the play, Time to decide, Presence of distractor	Correct answers, Omissions, Commissions
Soccer	Visual memory and working memory	A soccer field with players of two teams (Figure 1.f)	Screen touches	To connect dots repeating a sequence forwards or backwards	Time to decide, Number of sequences to increase the length	Correct answers, wrong answers
Duathlon	Divided attention	Split screen with marathon and cycling environments (Figure 1.g)	Two buttons: Todasdas grab To turn	To grab water and fruits while avoiding puddles and logs	Marathon: Lifetime of the items Cycling: Speed, Area of interaction	Correct answers, wrong answers of each event
Triathlon	Divided attention	Split screen with marathon and cycling environments and a pool with a swimmer (Figure 1.h)	Three buttons: To grab To flip To turn	To grab water and fruits while avoiding puddles and logs and flip turn	Marathon: Lifetime of the items Cycling: Speed, Area of interaction Swimming: Speed, Area of interaction	Correct answers, wrong answers of each event

Current issues and challenges in research on virtual reality therapy for children with neurodisability

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ABSTRACT

A PICO (population, intervention, comparison, outcome) approach is adopted to discuss issues and challenges in virtual reality therapy research in community health settings. Widespread variation within and between populations, e.g. co-morbid conditions, complicates treatment fidelity and applicability. Interventions require flexible dose and frequency to fit into children's family circumstances, with clearly employed specialist paediatric research staff. Comparisons require adaptation to digital technology, and keep pace with development. Outcomes may overstate the impact of virtual reality therapy and technological novelty, while not fully unpacking hidden digital effects. A wide set of agreed, flexible, and patient-centred outcome measures are required to establish positive clinical baseline.

1. INTRODUCTION

"As a parent I know that my child, along with others, is keen to engage with modern technology in most aspects of life, from assisting with school work, communicating with others and as a form of entertainment. If physiotherapy was delivered using a "computer games" format, I feel that my child would be much keener to engage in undertaking necessary tasks and exercises" (parent of child with cerebral palsy).

Virtual reality therapy (VRT) has required a massive investment from academic and clinical researchers, from time taken to develop technology, getting clearance for using technology that may be commercially produced, piloting the work, grant applications, analysis of results and to rollout of interventions. There are a vast number of pitfalls that can affect the outcome and quality of intervention. There are a number of patterns that continually re-appear, and here we present those, in relation to children with neurodisability, so as to help future research. These issues – perhaps unsurprisingly – fit into problems associated with the population (including within this individual variation), intervention, comparison, and outcome (PICO). Problems occur because of the population we are studying, the intervention we employ, the way we try and compare groups, and the outcomes we are seeking. This paper will therefore look at:

1. Population, and variation that occurs across individuals within groups e.g. co-morbidity, as well as between groups (e.g. Autism versus Cerebral Palsy).
2. Intervention – dose, frequency and therapist delivery
3. Comparison issues within method construction – e.g. placebo, novelty effect
4. Issues with outcome measures; their consistency, and how these are shaped by interaction with patient and public involvement (PPI) groups e.g. what parents tell us.

We use our own nationally (UK) funded feasibility study that looked at using the Nintendo Wii with children with Cerebral Palsy, outlined below, to ground our examples. We conclude with some pointers to tackle these problems.

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2. A FEASIBILITY STUDY OF VIRTUAL REALITY AS A THERAPEUTIC INTERVENTION IN CHILDREN WITH AMBULATORY CEREBRAL PALSY

This study (National Institute of Health Research for Patient Benefit Programme PB-PG-0613-31046, approved by National Health Service Research and Ethics Committee) looked at the feasibility of running a large-scale multi-centre study using the Nintendo Wii Fit to deliver regular home-based physiotherapy. Participating families completed a questionnaire regarding children's current use of computer games such as Nintendo Wii Fit within the home. Participating children were randomised into either a supported or unsupported (control) participant group. Supported participants followed a physiotherapist (PT) prescribed schedule over a 12-week period, utilising only specified Nintendo Wii Fit games for designated amounts of time per session. Sessions were recommended to last 30 minutes, three times a week with games selected for specific physiotherapy purposes, such as core stability or balance. During this 12-week period, fortnightly telephone contact to families oversaw the child's progress, updated game selection and responded to any queries in the PT supported group. The unsupported (control) participants were also asked to use the Nintendo Wii Fit for 30-minute sessions, 3 times a week, over a 12-week period. However, they had free choice over which games they chose and duration each game was to be played within the session. Scheduled phone contact was minimal to this group during the 12-week period, unless specific physiotherapy advice was required. Carers and children of both groups were required to keep a simple daily diary to rate the sessions. Assessments of balance and functional mobility were taken before commencing the trial, halfway through, and on completion. An exit questionnaire asked parents and children to report on factors such as engagement, ease of use and effects of fatigue. Factors that impacted on the choice of method are discussed in section 3.

3. ISSUES AND CHALLENGES WITH THE POPULATION

Children with neurodisability present in a number of ways, from disorders affecting movement, such as Cerebral Palsy (CP), Muscular Dystrophy and Developmental Coordination Disorder; to disorders of language and communication, including Autistic Spectrum Disorder; to broader disorders of global development, such as is seen in children with Downs syndrome. To further complicate matters these conditions can co-occur, for example children on the autistic spectrum will commonly also have Attention Deficit Hyperactivity Disorder and Developmental Coordination Disorder. Whilst for many children the cause of their disorder is uncertain, this is increasingly becoming identifiable, from known insults to the developing brain, including Fetal Alcohol Syndrome, Meningitis, extreme premature birth, Hypoxic Ischemic Encephalopathy, to genetic and chromosomal disorders such as Fragile X syndrome. In the UK most children with neurodisability are seen at community based Child Development Centres (CDCs), often utilising home or school based therapeutic interventions. More complex cases may be seen in a small number of specialist tertiary centres, which are often hospital based. Furthermore, there is a high level overlap between different diagnoses under the umbrella of neurodisability with children with CP at higher risk of social communication disorders and conversely, those on the autism spectrum at high risk of movement impairments (Green et al, 2009, Christensen et al, 2014). At present most neurodisability academics and research activity is based in the latter, begging the question of how to build a stronger research base in community centres focusing on how to improve practice in more common disorders (Morris et al, 2015).

Whilst there are pharmacological interventions that can help in some cases, for example the use of stimulant medication in Attention Deficit Hyperactivity Disorder, anticonvulsant medication in Epilepsy, or the emerging use of Gene splicing in Duchenne Muscular Dystrophy, it is rare for there to be a cure. Therefore, in most cases the mainstay of treatment is to ameliorate the impact of the condition through therapeutic intervention (Morris et al, 2015). Whilst programs of physiotherapy, occupational therapy, speech therapy or behaviour modification can all help, they often rely on parents or school to deliver much of the program and from parental feedback can result in significant stress within the family (Coombe et al, 2012). Eventually this may well lead to the child refusing to complete their therapy. In the design stage of our study using the Wii Fit to determine whether it could improve balance and movement in children with cerebral palsy, parental input made it clear that as much as physical outcomes were important, for parents the primary measure of success of the intervention would be whether home based therapy could be delivered regularly without the levels of stress they associated with any attempt to deliver standard physiotherapy.

Each condition presents its own challenges to VRT research, although in many cases might be expected to respond to therapy developed through virtual reality technologies. For the current generation of children, virtual reality and information technology is a world they are very familiar and comfortable with, whether gaming, communicating, accessing information or working (Prensky, 2001). It would not be surprising therefore if therapies delivered through virtual reality technologies should prove motivating for modern children. This is no more so than for children on the autistic spectrum, particularly those considered "high functioning", or diagnosed with Asperger's Syndrome, who are likely to be more comfortable interacting with technology than with their human peers, and indeed may well go on to work within the Information Technology industry (Murray et al, 2005). However, the challenges are very real.

Taking the example of Autistic Spectrum Disorder, there is an immediate issue over the breadth of the spectrum, from a child who may be non verbal with severe learning difficulties, to a "high functioning" child who may struggle understanding social interaction and be obsessive, yet at the same time have the genius to be a professor of maths, physics or computing, as portrayed in the TV character Sheldon Cooper (Big Bang Theory), or in Sherlock Holmes. As such designing a study for children with Autistic Spectrum Disorder immediately presents the question of which children within the spectrum the intervention is aimed at. For example we are currently developing a tool to support diagnostic assessment, incorporating a number of psychometric tests used in assessing school age children, into an App. We would anticipate that this is more likely to be helpful in children presenting at school age, and generally with a borderline to average academic ability, than those who are non verbal and with severe learning difficulties.

Similarly, interventions for children with cerebral palsy, need to take account that this "blanket" term, describing children with movement disorders resulting from a static brain insult occurring during early development, may present with different types of abnormal movement including spasticity and ataxia, and with a wide range of severity, from a child with a mild hemiplegia with minimal effect on movement, to a child with whole body involvement who is wheelchair dependent. With our Wii study this raised the question of which children to target. We chose to focus on children who are able to walk and therefore hopefully use the Wii Fit without having to use supportive technologies, e.g. standing frame, to even stand on the Wii Fit.

Regardless of diagnosis, engagement in therapeutic intervention may prove problematic (Coombe et al, 2012). In younger children, there may be issues over ability to access technologies, and to understand the research study enough to give assent. Teenagers by their nature may also choose to disengage, or may feel some Virtual Reality games are "no longer cool", and for younger children. The individual conditions present their own difficulties, for example offering a group intervention for children on the autistic spectrum may be doomed to failure. Research on intervention effects in paediatric neurodisability has been confounded by a number of differing behavioural approaches and defining outcomes. In the UK the James Lind Alliance - a leading charitable and academic think tank- recently determined the most important research questions in the field, helping set clearer agendas (Morris et al, 2015).

4. ISSUES AND CHALLENGES WITH THE INTERVENTION

Dose and frequency of an intervention employed in virtual rehabilitation is equally challenging, especially in community settings (James et al, 2015, Boyd et al, 2013). Community situations call for direct adaptations to family life, as emphasised in the International Classification of Functioning, Disability and Health – Children and Youth version (ICF-CY) where participation and activity performance across contexts is a key part of the framework (World_Health_Organisation, 2007). Acute settings e.g. hospitals are able to offer bespoke interventions but only in situ, whereas community settings are required to be more flexible in their approach to delivery of care. Therefore whilst variation in the amount of time spent on a therapy varies dramatically across the literature, those that have positive results are often lacking the sample size to justify clinically important differences (Tarakci et al, 2013), and those studies with a sufficient sample size sometimes show little clinically significant impact (Boyd et al, 2015), this is to be expected in a setting where social factors surrounding healthcare are equally as important as the treatment. A more personalised, adaptable, and consistent approach to treatment will only occur once VRT is adopted as regular care. Further, whilst VRT interventions are quite well classified (see Galvin and Levac, 2011), wider issues surrounding clinical research are more complex.

In our own present study, the intervention was developed using the Nintendo Wii Fit for use in the home for children with Cerebral Palsy. The Wii Fit was to be used three times a week, for thirty minutes, over a period of twelve weeks (following Chen et al, 2012) using the Wii Fit Plus set of games. Early results suggest that 12 weeks is possibly too long a period of time for the intervention as many families reported having struggled to "fit in" the intervention. Children were often ill, tired from school, away on holiday, having treatment such as botulinum toxin, or were busy with a full and active life. Many parents also pointed to a tipping point in motivation around the 8th week, a time-point echoed in the earlier work of Deutsch et al. (2008). After an active period of motivation it appears that interventions may lose novelty to the participant, and return to being just another form of physiotherapy. Future work may need to employ more flexible methods to allow for time points where children are ill, or away, and not become lost or missing data, allowing the current status of a participant to alter according to personal circumstance (Dempsey et al, 2015).

The intervention was dependent on delivery and monitoring by therapists. In the local community setting physiotherapists anecdotally had been using the Wii and the Wii Fit for many years, with focus groups developing programmes that were believed to target different areas of the body e.g. core strength, balance. Many physiotherapists were keen to become involved with the study but once the study was underway external pressures changed the landscape of delivery. Pressures on retention and recruitment of therapy staff reduced the time available, especially with an increased emphasis on delivering established clinical services. To that end it seems imperative that specialist staff is employed where possible in a full-time research capacity to ensure clear protocol adherence, and ensure planned study recruitment and continuity. In England, research costs such as a research assessor measuring outcomes, are covered by the National Institute of Health Research (NIHR). Costs associated with delivering an intervention such as treatment are conversely met by local National Health Service (NHS) organisations. As a result the tax funded NHS organisations may resist research that would involve the testing of innovative methods, especially if they take staff away from clinical services. To test new treatment methods, resources are therefore needed to 'backfill' staff so that specialist staff can be freed up to take part in research. Expecting regular staff to fit in research on top of regular daily clinical work does not work well in practice. To fully explore the impact of interventions with VRT the intervention needs to be run as if it were regular care, with fully employed clinical staff.

5. ISSUES AND CHALLENGES WITH APPROPRIATE COMPARISONS

Virtual rehabilitation and the use of new technology come with challenges to the creation of appropriate method. A variety of models are already being attempted, such as 'micro-RCTs' (Dempsey et al, 2015), the use of standard controls (e.g. James et al, 2015), treatment as normal (e.g. Ferguson et al, 2013), reduced support in the intervention group (i.e. prescribed treatment versus freedom to use kit where appropriate) or even the use of computer controls such as delivery of an intervention via another modality such as a handheld device when an interactive console is being used in the experimental group (e.g. Hondori et al, 2015). However, the underlying problem with new technology is that we do not know the impact of any hidden effects of technology. Hidden effects are well documented in discussions of the placebo effect within medical interventions (Brissonnet, 2011, Brown, 1998, Moerman and Jonas, 2002) but there is yet to be a methodological discussion of the impact of digital technology on the participants - as well as researchers - behaviour (Farr et al, in submission). For example, what (if any) is the effect of the make or branding of technology and intuitive design if an iPhone is used compared to another standard smartphone? What technology, and what technological bias might already be present in the home? For example prior to our intervention in the home we conducted a survey of home use and presence of commercially available consoles. Parents and patients agreed that the most common, most useful tool, across all gradations of cerebral palsy, and especially for fine motor skills was the iPad (Farr et al, 2015). Therefore it is highly unlikely that individuals will have no experience of digital technology whatsoever, so there may be an impact of *prior experience*, plus an impact of *novelty* where an intervention uses a brand new piece of technology. Technological novelty may simply boost the interest in an intervention, thereby overstating its impact (Zaczynski, 2013). Ensuring health behaviour change, without lapses in the impact, is still relatively new and in development (Klasjna et al, 2011).

Furthermore, rate and pace at which research and development occurs is mismatched (Pagoto and Bennett, 2013). This would be in keeping with Moore's law that predicts ever increasing memory expansion in technology (Moore, 1965). But there is a large disjuncture between the time it takes for research using new technological devices to occur, and the pace at which new devices are being produced, which means that it is difficult to validate devices and applications (Pagoto and Bennett, 2013). In addition, a shortfall in the accuracy of sensors can further complicate technological use, reducing the reliability of clinically relevant information obtained from devices (Steinberg et al, 2015). Therefore it is imperative that any teams that use digital technology in clinical research keep abreast of the latest technological developments, with the right team in place. For example, the National Health Service in England sought to create and establish a database of smartphone applications in 2013 so that it could begin to ensure validity and compliance to local health ethics and ensure data protection. This pilot is currently no longer live whilst the data is being used to create a new endorsement model for patient focused healthcare applications, research found though that 89% of applications were transmitting patient information to online services and without encrypted personal information (Huckvale et al, 2015). It is possible that some technology may still be more hype than hope (Labrique et al, 2013)

During the creation of methods of intervention for digital technology use in clinical settings it is apparent that there are as yet many unanswered questions over the hidden impact of technology, and technology is set to become only ever more pervasive in our daily lives. Therefore the development of appropriate comparisons is still in its infancy. The lag from development to clinical research and validation is lengthy, as a result some authors have called for ever more close-knit research teams between the field of human-computer interaction and clinical research (Klasjna et al, 2011). In our own research, tensions existed between using technology that was fast becoming dated and used less by the general population (the Nintendo Wii has been surpassed by the Xbox in research), and establishing an effective and complex intervention that employed a technology when so little is known about hidden benefits and barriers. Agile, novel and new comparative methods will be needed as community based populations take part in digitally based technological interventions. Micro-RCTs is one possible solution, as is the use of similar interventions in wings of studies, but with subtle variants (e.g. more versus less support as in our own study), until more is known about the direct benefits of digital usage.

6. ISSUES AND CHALLENGES: RESULTS AND OUTCOME MEASURES

Our own systematic review of VRT for children with motor disorders confirmed the lack of fully powered studies to show if this is a valid direction of future travel, whether using off the shelf gaming technologies such as the Wii Fit, Xbox, iPad; or expensive, one off bespoke systems (Farr and Male, 2013). Of the available studies in children with cerebral palsy, a couple of which included 20-30 children, most suggested some improvement in motor measures, with effect sizes of 0.3 to 0.8 (Sharan et al, 2012, Jelsma et al, 2012) however there was little agreement over which outcome measures to use, even when focused on a specific skill such as balance. One study showed significant clinical improvement in dynamic balance and other motor outcomes in 10 children with Progressive Spinocerebellar Ataxia using the Xbox Kinect (Ilg et al, 2012). This intervention was considered highly motivational and cost-efficient. Two studies gave promising results for the Wii Fit in children with Developmental Coordination Disorder (Hammond et al, 2013, Ferguson et al, 2013) including our own randomised control crossover pilot study based in a school setting, involving 19 children. Bruininks Oseretsky Test of Motor Proficiency Short Form (BOT-2), used as the main outcome, as a measure of improvement in motor coordination, improved in both groups during period of intervention, but fell close to baseline once the intervention finished (see figure one below for group 1 who had intervention first, then control period). Further measures included CSQ, a measure of the child's perception of their motor ability that also improved during intervention, but continued to do so even after intervention finished. Given that low self-esteem is such a common problem in children with Developmental Coordination Disorder, this may be as important as any actual improvement in motor coordination. SDQ, a measure of emotional wellbeing, was also included but very few parents completed this following intervention. In those that did, scores improved significantly, often with improving category from abnormal, or borderline, towards normal. This was particularly noticeable for the hyperactivity subscale.

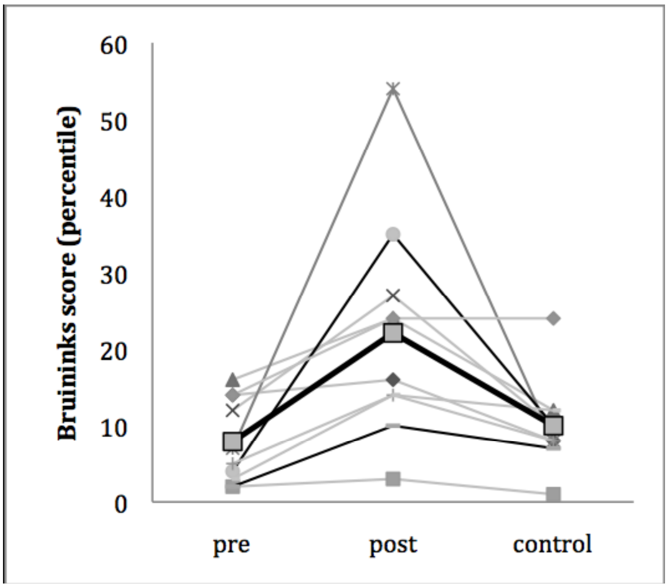

Figure 1. *Change in BOT-2 percentile for individual children using the Wii Fit as a treatment for DCD in a school setting; group A in a crossover study received intervention initially and then acted as controls. Mean result shown by thickened black line.*

Choice of outcome measure remains important, yet even in an area such as motor disability, where instinctively clinical measurement should be relatively straight forward, at least compared to measuring, for example, changes in social function in children with Autistic Spectrum disorder, there is no clear agreement over which measures to use. One of the key questions in our current Wii Fit feasibility study with children with Cerebral Palsy study has been to explore choice of outcome measure. From a motor perspective one would instinctively expect the Wii Fit, as a glorified balance board, to improve measures of balance, of which we chose the BOT-2 and Timed Up and Go Test. The former was developed for use in children with side of Developmental Coordination Disorder where poor balance is a frequent problem. In such children the better side is tested for example in testing fine motor coordination-whereas we have had to adapt this in children with unilateral Cerebral Palsy to also test the affected side. The Gross Motor Function Measurement (GMFM), a specific measure of motor function for children with Cerebral Palsy has also been used. Although the study is still in progress, it is evident that for some children with very mild Cerebral Palsy that they reach 100% on GMFM before completing the intervention (ceiling effect), whilst we had concerns that BOT-2 might see the opposite (floor effect) with children scoring 0 pre intervention. Some measures therefore with virtual rehabilitation have ceiling or floor effects (e.g. Gross Motor Function Measure) when being used across a disorder that has a wide gradation, such as Cerebral Palsy as graded by the Gross Motor Function Classification System.

The Goal Attainment Scale (GAS) has also demonstrated improvement in participating children, and mirrors clinical practice in therapeutic goal setting by personalising targets. However, goals set by each child will differ, so it is difficult to compare the degree of improvement in each child. Nevertheless, some of the individual stories of functional improvement are almost more persuasive of the benefits offered by VRT, than overall statistical analysis. For example, in this study one 12 year old boy improved from being unable to stand on one leg at all at the start of the study, to doing so successfully for 10 seconds by the end. Another 10-year old girl with hemiplegic Cerebral Palsy, involved in a one-week intensive pilot study using the Xbox Kinect for an hour a day for five days, focussing on upper limb function, reported with great excitement being able to do up her seatbelt for the first time in her life. As noted previously, measures of motor outcome are important to us as clinicians. However, for the family, impact of therapy on family life is an equally, or indeed, a more important outcome. For this study families have been encouraged to keep a diary exploring compliance with the protocol, but also to report difficulties in persuading the child to "do their exercises". Strengths and difficulties questionnaire (SDQ) has also been used as a measure of emotional wellbeing for the child. Hopefully by the end of the study it will be clearer which measures are most useful, to inform future study design, with the need for larger, probably multi-centre RCTs, needed to finally confirm whether VRT has a valid role within the therapeutic armoury for children with motor neurodisability. There is equal need for similar feasibility studies in other areas of neurodisability, for example to explore the potential of collaborative play when using the Xbox Kinect adventure games to improve social skills in children with Autistic Spectrum Disorder.

The issue of individual variation – discussed in section 2 – results in a wide spread of scores which could be due to co-morbidity or wide gradation across a developmental disorder. One solution for evaluation is through multiple case studies analysis, thereby highlighting individual variation but isolating the impact on personal health (e.g. Green and Wilson, 2011). For example during a study week where we assessed the potential benefits of the Xbox Kinect for upper limb function, one patient struggled following instructions due to his additional learning needs, and Attention Deficit Disorder. For example, whilst playing virtual bowling the child struggled to comprehend where the bowling ball went in space when the ball was virtually 'picked up'. On other tasks the child understood what to do but the notion of a 'virtual' ball was tricky to comprehend. Interestingly when the child was playing bowling on the Wii, demanding he hold and move the controller, it was much easier for him to grasp and use the ball with more proprioceptive feedback. His results therefore were not complete for the Xbox, but the outcome was useful in terms of what he was capable of doing. Another child with Cerebral Palsy and Autism, with oppositional defiant disorder, in the Wii Fit study, struggled to even get through any of the measurements with the physiotherapist. For the physiotherapist to be able to take any measurements a large amount of adaptation was used such as integrating other games into the session to ease the pressure on taking measurements. The child's parent eventually dropped out of that study due to stress when coming to clinic for measurements. Again, this child presented without results at the end of the 12-week Wii fit study, but there was a result in terms of study feasibility, in relation to age group, and the impact of co-morbid developmental disorders on the child's ability to adhere to measurement and study protocol.

7. CONCLUSIONS

We used a PICO (population, intervention, comparison, outcome) approach to discuss issues and challenges in virtual reality therapy research in community health settings. Future studies will need to be designed with sufficient power to prove, or disprove the effectiveness of VRT, and allow for children not completing studies, or consider excluding them from the onset if they are unlikely to complete. Therefore unexpected results and outcomes are to be somewhat expected in the process of community research, and are ultimately more naturalistic to how interventions would be employed in day-to-day life. But also, widespread variation exists within and between populations, complicating treatment fidelity and applicability, therefore necessitating care in sufficiently surveying populations with regards to technology before any intervention or experimentation takes place. Whilst traditional research methodologies such as the Gold Standard Double Blind Randomised Placebo Controlled Trial work well for example in studying a new medicine, the nature of Virtual Reality interventions makes this much harder to achieve. It will be important to learn the lessons of feasibility research such as described in this paper to enable studies that truly validate and hopefully justify the use of Virtual Reality Therapies in the future. Importantly, this would increase the evidence base underlying current practice in Paediatric Neurodisability.

Funding Acknowledgement. This project was funded by the National Institute for Health Research (Research for Patient Benefit Programme number: RfPB PB-PG-0613-31046)

Department of Health Disclaimer. The view and opinions expressed therein are those of the authors and do not necessarily reflect those of the RfPB NIHR programme, NIHR, NHS or the Department of Health.

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Using virtual interactive training agents with adults with autism and other developmental disabilities

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ABSTRACT

Conversational Virtual Human (VH) agents are increasingly being used to support role-play experiential learning across a range of use-cases and populations. This project examined whether use of the Virtual Interactive Training Agent (VITA) system would improve job interviewing skills in a sample of persons with autism or other developmental disability. The study examined performance differences between baseline and final interviews in face-to-face and virtual reality conditions, and whether statistically significant increases were demonstrated between interviewing conditions. Paired samples t-tests were utilized to examine mean changes in performance by interview stage and in the overall difference between baseline and final interview stages. The preliminary results indicated that VITA is a positive factor when preparing young adults with autism or other developmental disability for employment interviews. Statistically significant results were demonstrated across all pilot conditions and in all but one post-assessment condition.

1. INTRODUCTION

1.1 Adults with Autism Spectrum Disorder and Employment

While it is recognized that many persons with autism spectrum disorder (ASD) and other developmental disabilities have the necessary capabilities for success in employment, adults with ASD are noticeably underrepresented in employment when compared to the general population (Taylor & Seltzer, 2011). According to the United States Bureau of Labor Statistics (2014), the general population's employment rate was nearly 65%, which stands in sharp contrast to the employment rate of adults with ASD which was just over 17%. Taylor, Henniger, and Mailick (2015) conducted a study over a 12-year period that investigated post-secondary education and employment of adults with ASD. They found that while two-thirds of study participants were engaged in competitive employment and/or post-secondary education during at least one point during the longitudinal study, only 25% of the adults studied were steadily engaged in competitive employment and/or post-secondary education during the longitudinal study.

One step in attaining employment is participating in a job interview. Job interviews can be a significant source of anxiety for many adults in the general public (Rynes, Bretz, & Gerhart, as cited in McCarthy and Goffin, 2004). This is especially true for adults with autism who typically struggle with social anxiety (Maddox & White, 2015). This anxiety may limit their success in job seeking activities, including interviews.

McCarthy and Goffin posit that interview anxiety can be differentiated from typical anxiety tendencies. Interview anxiety may result in reduced confidence in the candidate's self-efficacy with interviewing (Tross & Maurer, 2008). Therefore, training to improve interviewing skills is warranted. Tross and Maurer found that training or coaching had a positive effect on subsequent individuals' interview performance.

1.2 Virtual Reality Technology

Ground-breaking advances in technology may provide a solution for addressing issues that inhibit adults with ASD from entering the work force. Virtual reality technology has long been used to treat anxiety disorders and other clinical health conditions. For example, Virtual Reality Exposure Therapy (VRET) uses a computer generated "virtual environment" (p. 251) to gradually expose clients to fear producing stimuli and contexts in a safe, contained setting that aims to promote extinction of fear and anxiety in persons with phobias and posttraumatic stress disorder (PTSD). In 2008, Parsons and Rizzo reviewed the literature on the use of VRET for reducing anxiety. The results of their meta-analysis showed that the VRET had a positive impact on reducing anxiety. This was supported in an independently conducted meta-analysis published around the same time by Powers and Emmelkamp (2008), in which the authors concluded that VRET is very effective in treating anxiety disorders, and in a more recent report (Opris et al., 2012).

As a result of cutting-edge progress in virtual reality (VR) technologies, the creation of low-cost systems that can run on a personal computer have been developed. This technology is becoming more accessible to the public at large and this trend is expected to continue. One example of this progress is in the creation of conversational virtual humans (VHs) capable of engaging in face-to-face dialogues with real users. Virtual humans have been used in a variety of situations for: training clinical skills (Rizzo, Kenny, & Parsons, 2011), addressing anxiety disorders (Parsons & Rizzo, 2008; Powers and Emmelkamp, 2008), improving body image in persons with eating disorders (Riva, 2011), and for supporting anonymous access to coaching support in persons with PTSD (Rizzo et al., 2015). This emerging use of VR technology sets the stage for the application of VHs to support the practice of vocational interviewing in a safe, virtual environment in order to improve social and communication skills. This may help to reduce anxiety by repeated exposure to the challenges perceived by participants in a real life job interview and provide users with realistic practice in the construction of interview responses.

A previous effort to use technology to improve interview skills in persons with ASD involved the JobTIPS web-based program (http://do2learn.com/JobTIPS). JobTIPS is an online multimedia program that provides a variety of vocational training resources including video models and interactive avatar-based practice (VH interviewer driven by a live clinician) for employment interview training using a platform similar to 2nd Life (Venugen, 2010). In a study of 22 participants, ages 16 to 19 with ASD, Strickland, Coles, and Southern (2013) found that the JobTIPS program along with a virtual reality practice session improved participants' ability to provide appropriate verbal responses to interview questions. However, delivery skills, defined by Strickland et al. as responses that measure posture, eye contact, and facial expressions, did not improve at the same level. Nevertheless, the study did show the benefit of using a home computer in practicing the employment-related interviewing skills needed for improving opportunities for employment. Similar encouraging results have been reported using another avatar-based interview training system (Kandalaft et al., 2013) and in two studies where ASD users responded to video clips of a human job interviewer via selection from a multiple choice menu of responses (Smith et al., 2014, 2015).

Similar to the above, the Virtual Interactive Training Agent (VITA) system was designed to give users on the autism spectrum the opportunity to practice job interview responding with a VH interviewer. The use of a 3D graphic VH approach was made to foster flexibility in the range of VH characters that could be delivered with the same underlying software and to support variations in VH personality and level of provocativeness. This is in line with the design perspective detailed by Lange et al. (2012), which described the essential features of rehabilitation tasks that also seem to hold true for skill-building. Lange deems these tasks *good* if they offered the ability to adjust difficulty levels, can be administered repeatedly, provided feedback, were quantifiable and relevant to the real world, and motivated the user. The VITA system supports all of these characteristics. The VITA system creates a virtual reality experience that provides a comprehensive and hierarchical set of job interview practice experiences with VH interviewers that users can interact with as part of the interview training process. VITA provides a platform where participants can practice job interviewing with VH agents that are capable of asking a variety of questions in an assortment of settings. This opportunity for users to repeatedly practice job interviewing can be adjusted across a spectrum of challenges. It was hypothesized that users with a developmental disability would significantly improve their interviewing skill with repeated practice in this type of training.

1.3 Virtual Interactive Training Agent

The Virtual Interactive Training Agent (VITA) is an interactive VR job interview practice system for building competence and reducing anxiety in young adults with autism spectrum disorder (ASD) and other developmental disabilities. The VITA system was originally commissioned by The Dan Marino Foundation (DMF: http://www.danmarinofoundation.org/portal/) as a research project in conjunction with the Florida Department of Education's Department of Vocational Rehabilitation and was developed at the University of Southern California's Institute for Creative Technologies (ICT). It is currently being used at DMF's innovative post-secondary institution and its use is now an integral part of the DMF Inclusive Transition and Employment Management (ITEM) program.

In order to produce a variety of experiences, six different VHs were created: three male and three female of varying ages and ethnic backgrounds (see Figure 1). Each VH can exhibit three behavioral dispositions: soft-touch, neutral, and hostile and is capable of asking 10 to 12 interview questions. Seven different interchangeable backgrounds set situational context that closely aligns with participants' specific employment interests. Hotel lobby, business office, and warehouse breakroom are among the settings available from the initial menu interface. The system provides a wide variety of distinct training opportunities for a range of job interview interactions that can progress in difficulty level and be adjusted to the specific needs of the user. The list of interview questions was derived from the agency's experience with vocational job interviews and by searching predictable interview questions on the internet. All VITA interviews were video recorded to provide an opportunity for student-led feedback sessions as part of the classroom curriculum.

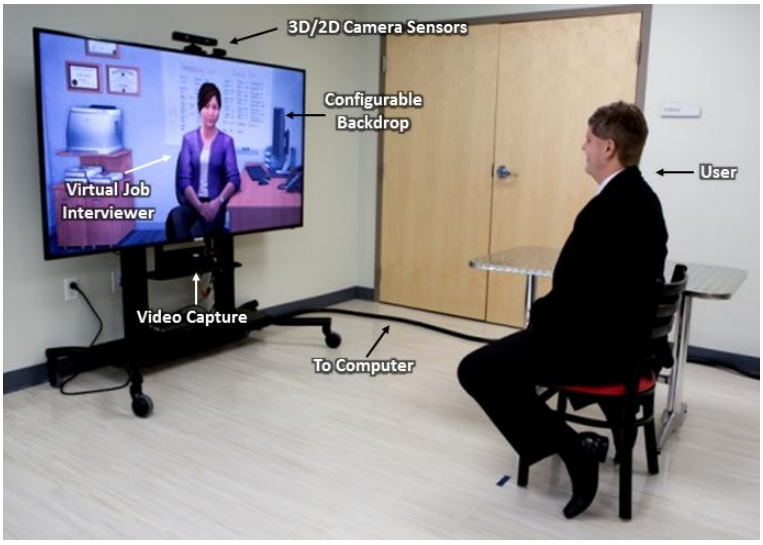

Figure 1. *User interacting with components of the VITA system.*

1.4 VITA Curriculum

In order to address the employment interview preparation needs of young adults with autism and other developmental disabilities, the ITEM program was implemented. Through this project, the VITA system was created to provide practice in job interview skills across a variety of easy to challenging interview conditions. Participants also engaged in coursework developed by DMF staff. This was based on the perceived need for participants to learn core interviewing and other employment skills prior to and during the VITA interventions. Lessons were also created that addressed interview etiquette such as greetings, acceptable small talk, and closing or thanking the interviewer.

The curriculum also included instructional strategies that taught ways to respond to a variety of questions typically asked during interviews. The instructors and curriculum developers of the course determined that interview questions commonly take a predictable structure. This interview structure, or arc, informed the development of the curriculum and was later used to create the VH's script used during all interviews. This offered a level of cohesiveness and fidelity throughout the study. The interview arc used throughout the course, as well as throughout the VITA system, is a set of 10-12 questions that (a) ask participants to engage in social mores and introductory statements; (b) emphasize participants' strengths and self-advocacy; (c) provide opportunities for self-promotion; (d) allow for a situational or behavioral example; (e) focus on general housekeeping; and (f) alert the participant that the interview is coming to a close.

Additionally, the course focused on explicitly teaching participants how to make a good first impression, provide clear and concise responses, self-promote by identifying individual strengths, engage in active listening, and convey interest using verbal and non-verbal communication. In order to capture students' performance of these skills, a standard in-house interview performance measure was created by the DMF staff. The Marino Interview Assessment Scale (MIAS) is designed to measure the degree to which the participant utilized these skills in an interview setting. Participants scored a 1 if they did not use a strategy that was called for given a specific question. A score of 2 indicated that skill was still in the beginning stages of implementation while a 3 indicated that the skill was developing; 4s indicated that the interviewee adequately used the skill or strategy.

The highest score, 5, indicated that the participant was accomplished at the strategy. This project sought to examine whether use of the VITA system provided a statistically significant increase in mean MIAS scores from baseline interviewing in both face-to-face and VR conditions to final face-to-face interviews, and whether a statistically significant increase was demonstrated between interviewing conditions.

2. METHODS

2.1 Participants

The ITEM program and a simultaneous project, entitled The Jobs Development Program, were housed at the newly constructed, state-of-the-art Marino Campus facility located in downtown Fort Lauderdale. These projects recruited local Vocational Rehabilitation clients who utilized DMF as their local vendor. Additionally, the project included participants from local public high schools as part of a community based instructional (CBI) site. The participants ranged in age from 18 to 28 years old with the mean age of 23; 77% were male, 23% female. All participants had a documented disability as evidenced by psychological reports provided by the participants and/or their families; 63% were diagnosed with ASD while the remainder had other developmental disabilities. There were 96 participants at the start of the study. Some of the original participants either gained employment or left the program for other reasons. In those instances, participants' data were removed from the study. In all, data were analyzed from over 64 participants' interview performances.

The following year, 16 students from an exceptional student education program at a local high school participated in a post-pilot study. The students ranged in age from 17 to 22 years old; 69% were male, 31% female. Specific disability diagnoses were not collected.

2.2 Procedures

Before engaging in the VITA curriculum or using the VITA system, participants took part in a face-to-face interview conducted by a DMF staff member. During the interview session, a researcher captured the degree to which the interviewee met specific interviewing criteria as indicated on the MIAS. The sum of each individual's score was recorded. Shortly after the baseline face-to-face interview, an initial VITA session was conducted to determine the baseline score for each individual. Performances from this baseline VITA interview were also scored using the MIAS.

In all, there were six stages of data collection during the study: baseline face-to-face interview, baseline VITA session interview, three VITA intervention sessions, and a final face-to-face interview. At each stage, researchers observed the interview sessions and scored participant performances using the MIAS. The sums from each MIAS score were then averaged to determine not only individual progress but to determine group means as well.

Participants met for coursework twice each week over the course of the 14 week program. The final 5 weeks were dedicated VITA as an intervention in conjunction with course work. The curriculum focused explicitly on teaching participants interviewing skills that they could use when practicing with VITA and in a real interview. Individual lessons centered on making a good first impression, providing clear and concise responses, self-promoting by identifying individual strengths, engaging in active listening, and conveying interest using verbal and non-verbal communication.

In the post-pilot study, the students participated in a similar curriculum twice each week for 10 weeks, approximately 20 hours of curriculum. As in the pilot study, baseline and final face-to-face interview data were collected. However, only two VITA intervention sessions were conducted due to time constraints. At each stage, researchers observed the interview sessions and scored participants' performances using the MIAS.

2.3 Data collection

Prior to course work, all participants were observed during a baseline traditional interview (face-to-face). Performances were recorded using the MIAS developed to measure participant interview performance. The initial scores were recorded as Baseline 1.

In late March of 2014, the virtual reality hardware and software program was installed at the campus. Throughout April and May of 2014, all participants interviewed with the VITA system. Participants completed four VITA interviews; the first one is considered the baseline with three additional sessions. The researchers observed each interview and scored the interview performance using the MIAS. Finally, all participants were interviewed face-to-face and MIAS scores were collected. These interviews were conducted to see if there was an improvement between the two traditional (face-to-face) interviews, baseline and final, with the VITA system used as an intervention. These face-to-face interviews are to be considered the participants' pre- and post-assessments. In the post-pilot, pre/post interview data and two VITA session data were collected using the MIAS.

3. RESULTS

3.1 VITA Intervention

Paired-samples *t*-tests were conducted to compare MIAS scores from the final face-to-face interview to previous interviewing conditions and baselines in the pilot study. As expected, there was not a significant difference in face-to-face baseline scores (M=1.989, SD=.599) and (M=1.996, SD=.509) the VITA baseline, t(90)=-.112, p=.911. There was a significant difference in the scores for VITA baseline scores (M=1.996, SD=.509) and (M=2.69, SD=.735) the first VITA interview, t(88)= -9.255, p =0.00. A statistically significant difference in the scores from the first VITA interview (M=2.70, SD=.734) and the second VITA interview (M=3.20, SD=.724), t(86)= -9.814, p =0.00, was realized, demonstrating an improvement between those two conditions.

An improvement between conditions continued to materialize as demonstrated by a statistically significant difference in the scores between the second VITA interview (M=3.28, SD=.682) and the third VITA interview (M=3.64, SD=.856), t(65)= -4.247, p =0.00. When the third VITA interview (M=3.53, SD=.838) was compared to the final face-to-face interview (M=3.76, SD=.942), a statistically significant result remained, t(56)= -2.173, p=0.034.

The improvement of participants' interviewing competency over the course of this program was crystalized when the baseline and final scores were taken into account. The difference between both conditions was significant at p=0.00, providing evidence for the effectiveness of utilization of VITA for vocational interviewing with adults with autism and other developmental disabilities. Paired sample correlations are displayed in Table 1 and *t*-tests are displayed in Table 2.

A year following the initial VITA pilot, a smaller (n=16) post-pilot examined baseline interviewing skills. Paired-samples *t*-tests were conducted to compare the final face-to-face interview to previous interviewing conditions and baselines in the pilot study. There was no difference between the results of the first face-to-face interview and the first VITA interview. There was, however, a significant difference in the scores from the first VITA interview (M=2.313, SD=.624) and the second VITA interview (M=3.062, SD=.610), t(15)= -4.226, p=0.01. A statistically significant difference in the scores between the face-to-face baseline interview (M=2.31, SD=.202) and the second VITA interview (M=3.06, SD=.152), t(15)= --4.139, p =0.01, was shown, demonstrating an improvement from baseline.

When the second VITA interview (M=3.06, SD=.152) was compared to the final face-to-face interview (M=3.09, SD=.204), there was not a statistically significant result, t(15)= -.190, p=0.852. The difference between the face-to-face baseline (M=2.31, SD=.202) and face-to-face final interview (M=3.09, SD=.204) was statistically significant, t(15)= -3.411, p=.004, signaling a substantial improvement over the course of the VITA intervention. Paired sample correlations are displayed in Table 3 and t-tests are displayed in Table 4.

Table 1. *Paired Samples Correlations – Pilot.*

		N	Correlation	Sig.
Pair 1	Face-to-face baseline & VITA_Baseline	91	.493	.000
Pair 2	VITA_Baseline & VITA1	89	.410	.000
Pair 3	VITA1 & VITA2	87	.787	.000
Pair 4	VITA2 & VITA3	66	.632	.000
Pair 5	VITA3 & FF Final	57	.621	.000
Pair 6	Face-to-face baseline & FF Final	57	.660	.000
Pair 7	VITA_Baseline & FF Final	57	.365	.005

Table 2. *Paired Samples t-test – Pilot.*

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval				
					Lower	Upper			
Pair 1	Face-to-face baseline - VITA_Baseline	-.00659	.56289	.05901	-.12382	.11063	-.112	90	.911
Pair 2	VITA_Baseline - VITA1	-.68989	.70325	.07454	-.83803	-.54175	-9.255	88	.000
Pair 3	VITA1 - VITA2	-.50115	.47630	.05106	-.60266	-.39964	-9.814	86	.000
Pair 4	VITA2 - VITA3	-.35455	.67827	.08349	-.52129	-.18780	-4.247	65	.000
Pair 5	VITA3 – Face-to-face final	-.22456	.78017	.10334	-.43157	-.01755	-2.173	56	.034
Pair 6	Face-to-face baseline – Face-to-face final	-1.7579	.70886	.09389	-1.94598	-1.56981	-18.723	56	.000
Pair 7	VITA_Baseline - FF Final	-1.8281	.88110	.11670	-2.06186	-1.59428	-15.664	56	.000

Table 3. *Post-Pilot – Bivariate Correlations.*

		N	Correlation	Sig.
Pair 1	FF_Baseline & VITA_1	16	-.275	.303
Pair 2	FF_Baseline & VITA_2	16	.509	.044
Pair 3	VITA_1 & VITA_2	16	.338	.201
Pair 4	VITA_2 & FF_Final	16	.765	.001
Pair 5	FF_Baseline & FF_Final	16	.375	.152

Table 4. *Post-Pilot Paired Samples t-test.*

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval				
					Lower	Upper			
Pair 1	FF_Baseline - VITA_1	.00000	1.15007	.28752	-.61283	.61283	.000	15	1.000
Pair 2	FF_Baseline - VITA_2	-.75000	.72480	.18120	-1.13622	-.36378	-4.139	15	.001
Pair 3	VITA_1 - VITA_2	-.75000	.70993	.17748	-1.12829	-.37171	-4.226	15	.001
Pair 4	VITA_2 - FF_Final	-.02500	.52599	.13150	-.30528	.25528	-.190	15	.852
Pair 5	FF_Baseline - FF_Final	-.77500	.90885	.22721	-1.25929	-.29071	-3.411	15	.004

4. DISCUSSION

These preliminary results indicate that the VITA system is a positive factor for preparing young adults with autism and other disabilities for employment interviews. Participant baseline interviews and VITA baseline interview scores showed no significant difference, which may indicate that participants interviewing skills were captured similarly in both the traditional face-to-face style of interview and the VITA virtual reality interview.

This is important because improved VITA interview performances led to improved face-to-face interview outcomes.

Statistically significant results were demonstrated across all pilot conditions, and in all but one condition in the post-pilot study. The exception is a demonstrable improvement between the second VITA interview and final face-to-face measurement, signaling that all relevant skills were gained in the first VITA post-pilot interview and no further practice was necessary before the final face-to-face interview. This could be due to fewer VITA sessions conducted or the shorter time frame for project implementation and data collection during the post-pilot study.

Improvement was demonstrated across all other conditions, suggesting that in the pilot stages, each new encounter and practice session with VITA created a statistically significant improvement. The improvement in the final stage exceeded all previous stages in the pilot condition, demonstrating that the program, in its current format, can create a measureable and significant improvement in the interviewing skills of participants. While the results from this study show that VITA is influential in improving interviewing skills of young adults with autism and other developmental disabilities, further investigations could determine the impact of the companion curriculum. The results from this study cannot determine the effectiveness of the VITA system alone; however, results do indicate that the VITA system, in conjunction with explicit training and teaching, is a powerful intervention. With consistent use, this tool could be a positive influence in increasing the number of adults with disabilities in gaining meaningful employment.

5. CONCLUSIONS

VITA provides a platform where job interviewing skills can be practiced using VHs to provide the interview questions for participants to practice their responses. As a result of their participation in this study, participants enhanced their skill with interviewing by improving the manner in which they respond to typical interview questions. Data indicate that participants developed their ability to identify individual strengths, engage in self-promotion, engage in self-advocacy, answer situational questions, and respond to behavioral or social questions and to self-promote as measured by multiple evaluations using the MIAS. The result of the practice using VITA was improved job interviewing skills for individuals with developmental disabilities.

The VITA curriculum may be useful with regard to gaining prior knowledge and extending the participants' understanding of interview etiquette and interview expectation. Further research can be extended to investigate whether VITA would be as effective without the embedded curriculum or how much benefit VITA adds to it. The current study utilized three VITA intervention sessions. Additional research could help determine the quantity, duration, and frequency of VITA interventions that provide the most effective results. Finally, new research is planned to determine the degree to which the participants believe that they have the skill and confidence during an interview setting and whether that self-efficacy has an impact on interview performance as a result of training with VITA.

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Clinical interviewing by a virtual human agent with automatic behavior analysis

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ABSTRACT

SimSensei is a Virtual Human (VH) interviewing platform that uses off-the-shelf sensors (i.e., webcams, Microsoft Kinect and a microphone) to capture and interpret real-time audiovisual behavioral signals from users interacting with the VH system. The system was specifically designed for clinical interviewing and health care support by providing a face-to-face interaction between a user and a VH that can automatically react to the inferred state of the user through analysis of behavioral signals gleaned from the user's facial expressions, body gestures and vocal parameters. Akin to how non-verbal behavioral signals have an impact on human-to-human interaction and communication, SimSensei aims to capture and infer user state from signals generated from user non-verbal communication to improve engagement between a VH and a user and to quantify user state from the data captured across a 20 minute interview. As well, previous research with SimSensei indicates that users engaging with this automated system, have less fear of evaluation and self-disclose more personal information compared to when they believe the VH agent is actually an avatar being operated by a "wizard of oz" human-in-the-loop (Lucas et al., 2014). The current study presents results from a sample of military service members (SMs) who were interviewed within the SimSensei system before and after a deployment to Afghanistan. Results indicate that SMs reveal more PTSD symptoms to the SimSensei VH agent than they self-report on the Post Deployment Health Assessment. Pre/Post deployment facial expression analysis indicated more sad expressions and fewer happy expressions at post deployment.

1. INTRODUCTION

Over the last 20 years, a gradual revolution has taken place in the use of Virtual Reality (VR) simulation technology for clinical purposes. When discussion of the potential use of VR applications for human research and clinical intervention first emerged in the early 1990s, the technology needed to deliver on this "vision" was not in place. Consequently, during these early years VR suffered from a somewhat imbalanced "expectation-to-delivery" ratio, as most who explored VR systems during that time will attest. However, in the last few years the accelerating pace technology development has now led to the creation of VR systems that have caught up with the vision for its clinical use as articulated by scientists in the 1990's. Dramatic advances in the underlying VR enabling technologies (e.g., computational speed, 3D graphics rendering, audio/visual/haptic displays, user interfaces/tracking, voice recognition, intelligent agents, and authoring software, etc.) have supported the creation of low-cost, yet sophisticated VR systems capable of running on commodity level personal computers, and even on mobile devices like the *Samsung Gear VR*. In part driven by the digital gaming and entertainment sectors, and a near insatiable global demand for mobile and networked consumer products, such advances in technological "prowess" and accessibility have provided the hardware and software platforms needed to produce more usable and hi-fidelity VR scenarios for the conduct of human research and clinical intervention. Thus, evolving behavioral health applications can now usefully leverage the interactive and immersive assets that VR affords as the technology continues to get faster, better and cheaper moving into the 21st Century. While some of this may be due to the commercial enthusiasm generated by the Facebook purchase of Oculus Rift for 2 billion dollars, it is more likely that the highly publicized advances in the enabling technologies for delivering low cost VR simulations has sparked renewed public awareness and enchantment with VR. As well, a solid scientific literature has evolved documenting the value of applying simulation technology to usefully study and address the needs of people with a wide range of clinical health conditions.

These advances in the technical and scientific landscape have now set the stage for the next major movement in Clinical Virtual Reality with the "birth" of intelligent virtual human (VH) agents. This has been driven by seminal research and development leading to the creation of highly interactive, artificially intelligent, and natural language capable VHs that can engage real human users in a credible fashion (Swartout et al. 2013). Such intelligent VH agents have been created that control computer generated bodies and can interact with users through natural language speech and gesture in virtual environments (Gratch et al., 2002, 2013; Rizzo, Kenny & Parsons, 2011; Rizzo & Talbot, 2016a; Talbot et al., 2012). Advanced VH agents can engage in rich conversations (Traum et al., 2008), recognize nonverbal cues (Morency et al., 2008; Scherer et al., 2014; Rizzo et al., 2015, 2016ab), improve interactional rapport with users (Park et al., 2013) reason about social and emotional factors (Gratch and Marsella, 2004), and synthesize human communication and nonverbal expressions (Thiebaux et al., 2008). Such efforts have led to the creation of VH systems across a number of fields, including education, clinical training, clinical assessment and providing healthcare guidance. These findings have motivated R&D in our lab focused on the development of VH agent systems that serve as: virtual patients for training novice clinicians (Talbot et al., 2012; Rizzo et al., 2011, 2016a), clinical interviewers to reduce stigma (Rizzo et al., 2015), and as health care guides and clinical support agents (Rizzo et al. 2015).

In the area of clinical assessment, VH's can conduct clinically-oriented interviews within a safe non-judgmental context which may encourage honest disclosure of important information. In a recent study, users reported less concern about being evaluated and disclosed and displayed more sadness in an interview with a VH agent compared to interacting with a VH avatar that they believed was being operated by a human-in-the-loop "Wizard of Oz" controller (Lucas et al., 2014). VH agents have also been shown to promote engagement and longer participation with users asked to answer general questions posed on a mobile application compared to voice only and voice plus static VH image conditions (Kang et al., 2014) and this is in line with other studies indicating higher levels of personal self-discloser when VH agents are used in this form (Kang et al., 2012, 2013). Finally, users interacting with a conversational VH interface to access online health information were more satisfied compared to a conventional Web form-based interface and users with low health literacy were more successful (and satisfied) in their capacity to find information on available clinical trials when supported by a VH agent (Bickmore et al., 2016). Such findings converge to support the idea that users will disclose more and may also have enhanced success in accessing information when interacting with a VH-supported healthcare application.

The incorporation of a VH within the application detailed in the current paper is intended to amplify the effects reported in earlier studies that suggest that computer-mediated interviews are felt to be more anonymous than face-to-face interviews and this resultant anonymity leads to increased disclosure (Weisband & Kiesler, 1996; Baker, 1992; Beckenbach, 1995; Joinson, 2001; Sebestik, Zelon, DeWitt, O'Reilly & McGowan, 1988; van der Heijden, Van Gils, Bouts, & Hox, 2000). The impact of computer-administered VH interviews on the enhancement of disclosure is particularly relevant in health contexts due to the intimate nature of the information revealed. Effects are strongest when the information is illegal, unethical, or culturally stigmatized (e.g., drug use, unsafe sex, suicidal ideation) (Weisband & Kiesler, 1996; van der Heijden, Van Gils, Bouts, & Hox, 2000), which is critical information to disclose in health settings and where a patient's failure to provide honest and adequately detailed responses in medical interviews could lead to serious negative health outcomes when vital information is withheld.

This paper will detail our efforts in the creation of a VH who can serve in the role of a clinical interviewer (i.e., *SimSensei*) while also using camera and audio sensors to automatically detect behavioral signals from which user state may be inferred. The SimSensei system was specifically designed for clinical interviewing and health care support by providing a face-to-face interaction between a user and a VH that can automatically react to the inferred state of the user through analysis of behavioral signals gleaned from the user's facial expressions, body gestures and vocal parameters. User behavior is captured and quantified using a range of off-the-shelf sensors (i.e., webcams, Microsoft Kinect and a microphone). Akin to how non-verbal behavioral signals have an impact on human-to-human interaction and communication, SimSensei aims to capture and infer user state from signals generated from user non-verbal communication to improve engagement between a VH and a user. The system also can quantify and interpret sensed behavioral signals longitudinally for use to inform diagnostic assessment within a clinical context.

The development of SimSensei required a thorough awareness of the literature on emotional expression and communication. It has long been recognized that facial expression and body gestures play an important role in human communicative signaling (Ekman & Rosenberg, 1997). As well, vocal characteristics (e.g., prosody, pitch variation, etc.) have been reported to provide additive information regarding the "state" of the speaker beyond the actual language content of the speech (Pentland et al., 2009). Pentland (2008) has characterized these elements of behavioral expression as "Honest Signals" and posits that the physical properties of this signaling behavior are constantly activated, not simply as a back channel or complement to our conscious language, but rather as a separate communication network. It is conjectured that these signaling behaviors, perhaps evolved from ancient primate non-verbal communication mechanisms, provide a useful window into our intentions, goals, values and emotional state. From this perspective, an intriguing case can be made for the development of a computer-based sensing system that can capture and quantify such behavior, and using that data, make inferences as to a user's cognitive and emotional state. Inferences from these sensed signals could then be used to supplement information that is garnered exclusively from the literal content of speech.

Recent progress in low cost sensing technologies and computer vision methods has now driven this vision to reality. Indeed, recent widespread availability of low cost sensors (webcams, Microsoft Kinect, microphones) combined with software advances for facial feature tracking, articulated body tracking, and voice analytics (Baltrusaitis et al., 2012; Morency et al., 2008; Whitehill et al. 2009) has opened the door to new applications for automatic nonverbal behavior analysis. This sensing, quantification and inference from nonverbal behavioral cues can serve to provide input to an interactive virtual human interviewer that can respond with follow-up questions that leverage inferred indicators of user distress or anxiety during a short interview. This is the primary concept that underlies the SimSensei interviewing agent (See Figure 1). The SimSensei capability to accomplish this is supported by the "MultiSense" perception system (Morency, 2010; Devault et al., 2014; Scherer et al., 2014), a multimodal system that allows for real-time synchronized capture, tracking, and fusion of behavioral markers of different modalities such as audio as well as visual. MultiSense's fusion enables the analysis of complex behavioral indicators of user states across multiple modalities. Within SimSensei, MultiSense fuses information from a web camera, Microsoft Kinect and audio capture to identify the presence of predetermined nonverbal indicators of psychological distress. Dynamic capture and quantification of behavioral signals are used such as 3D head position and orientation, type, intensity and frequency of facial expressions of emotion (e.g., fear, anger, disgust and joy), fidgeting, slumped body posture, along with a variety of speech parameters (e.g., speaking fraction, latency to respond). These informative behavioral signals serve two purposes. First, they produce the capability of analyzing the occurrence and quantity of behaviors to inform detection of psychological state. Second, they are broadcast to other software components of the SimSensei system to inform the VH interviewer of the state and actions of the participant. This information is then used by the VH to assist with turn taking, rapport building (e.g., utterances, acknowledging gestures/facial expressions), and to drive and deliver follow-on questions.

Figure 1. *User with SimSensei virtual clinical interviewer.*

SimSensei is one application component developed from the DARPA-funded "Detection and Computational Analysis of Psychological Signals (DCAPS)" project. This DCAPS application has aimed to explore the feasibility of creating "empathic" virtual human health agents for use as clinical interviewers and to aid in mental health screening. The system seeks to combine the advantages of traditional web-based self-administered screening (Scherer et al., 2014), which allows for anonymity, with anthropomorphic interfaces which may foster some of the beneficial social effects of face-to-face interactions (Weisband & Kiesler, 1996). When the SimSensei system is administered in a private kiosk-based setting, it is envisioned to conduct a clinical interview with a patient who may be initially hesitant or resistant to interacting with a live mental health care provider. SimSensei's real time sensing of user behavior aims to identify behaviors associated with anxiety, depression or PTSD. Such behavioral signals are sensed and inferences are made to quantify user state across an interview; that information is also used in real time to update the style and content of the SimSensei follow-up questions. Technical details of the Multisense software as well as the SimSensei dialog management, natural language system, and agent face/body gesture generation methods are beyond the scope of this paper and can be found elsewhere (Devault et al., 2014; Scherer et al., 2014). Instead, we focus on the usefulness of SimSensei in collecting *honest* health information and behavioral markers of distress during a clinical interview with active duty Service Members (SMs) prior to and immediately following a 9-month deployment to Afghanistan.

2. METHODS AND PROCEDURE

2.1 Participants

Twenty nine (2 female) active duty members of the Colorado National Guard volunteered for this study prior to embarking on a 9-month deployment to Afghanistan. They were a diverse sample regarding age (Mean=41.46, Range=26 to 56) and previous deployments (Number of combat deployments Mean=2.00, Range=1 to 7).

2.2 Assessment Instruments

The study compared the endorsement of Posttraumatic Stress (PTS) symptoms in three formats: 1) standard administration of the Post-Deployment Health Assessment (PDHA) upon return from deployment; 2) an anonymized version of the PDHA; 3) parallel SimSensei interview questions. The PDHA administered upon return from a military deployment is a self-report rating scale designed to assess a service member's current health, mental health or psychosocial issues commonly associated with deployments, special medications taken during the deployment, and possible deployment-related occupational/environmental exposures. Participants signed releases to access their official web-based PDHA that they submitted to the National Guard upon return from this deployment. On the PDHA, participants are asked self-report PTSD-relevant symptom questions "Have you ever had any experience that was so frightening, horrible, or upsetting that, in the past month, you: A) have had nightmares about it or thought about it when you did not want to?, B) tried hard not to think about it or went out of your way to avoid situations that remind you of it?, and C) were constantly on guard, watchful, or easily startled?" These questions assess whether the SM is experiencing the core DSM-4TR diagnostic symptoms for PTSD (intrusive recollections/re-experienceing; avoidance/numbing; hyperarousal). Participants selected "yes" or "no" on each item of the official PDHA and our anonymized version.

The questions SimSensei asked on these topics were worded slightly differently to embed them in the interview without having the VH simply recite the PDHA. Participants were asked: "Can you tell me about an experience you had in the past few months that challenged you on an emotional level?" (trauma event criterion), followed by "Can you tell me about any bad dreams you've had about your experiences, or times when thoughts or memories just keep going through your head when you wish they wouldn't?" (intrusive recollection criterion), "Tell me about any times you found yourself actively trying to avoid thoughts or situations that remind you of past events," (avoidance/numbing criterion) and "Can you tell me about any times recently when you felt jumpy or easily startled?" (hyperarousal). As described in Scherer et al., (2014), MultiSense quantifies facial affect levels (positive, worry/fear), ranging from 0 to 100, where 0 is the absence of the emotion and 100 a strong emotion. Self-reports of these emotions were also elicited: "I am happy" and "I worry too much" were rated on 4 point scales from *never* to *always*.

2.3 Procedure

Participants completed our anonymous PDHA and SimSensei measures both before and after deploying (The official PDHA by definition was only administered at post-deployment). After giving consent, participants completed demographic questions as well as a number of measures described elsewhere (DeVault et al., 2014) and not presented in this paper. The confidentiality of all these measures was stressed. Participants then engaged in an interview with the SimSensei VH who conducted a semi-structured screening interview with a user via spoken language. The interview is structured around a series of agent-initiated questions organized into phases: initially there is a rapport-building phase where the agent asks general introductory questions (e.g., "Where are you from originally?"); this is followed by a clinical phase where the agent asks a series of questions about symptoms (e.g., "How easy is it for you to get a good night's sleep?"), which include the naturally embedded PDHA questions; finally, the agent ends with questions designed to return the patient to a more positive mood (e.g., "What are you most proud of?"). At each phase, the agent can ask follow-up questions (e.g., "Can you tell me more about that?"), provide empathetic feedback (e.g., "I'm sorry to hear that"), and produce nonverbal behaviors (e.g., nods, expressions) for active listening. Participants' answers to the three PDHA questions during the interview were coded by two blind coders as to whether the participant was rating symptoms based on an experience in the last month (per criterion of the PDHA questions). These coders had 100% agreement, and codes served as "yes" or "no" answers.

3. RESULTS

To test whether responses to the three versions of the PDHA (official PDHA, Anonymized PDHA, and SimSensei) differed, scores were created for each version by counting the number of "yes" answers to the three questions, which could range from 0 to 3. To compare these scores, we conducted a repeated-measures ANOVA using the 24 participants who successfully completed all three versions. There was a significant effect of assessment type, $F(2, 23) = 4.29$, $p = .02$ (see Figure 2). Follow-up contrasts revealed that participants reported more symptoms of PTSD (responded "yes" on more questions) when asked by SimSensei ($M = 0.79$, $SE = 0.23$) than when reporting on the official PDHA ($M = 0.25$, $SE = 0.15$)), $F(1, 23) = 7.38$, $p = .01$, or even when reporting on our anonymized version of the PDHA ($M = 0.33$, $SE = 0.16$), $F(1, 23) = 4.84$, $p = .04$. Moreover, unlike a previous study where anonymity increased reporting of symptoms (Warner et al., 2011), our analysis of this sample did not reveal differences between official and anonymized versions of the PDHA, $F(1, 23) = 0.19$, $p = .66$, yet did reveal significantly more endorsement of symptoms with SimSensei compared to these forms.

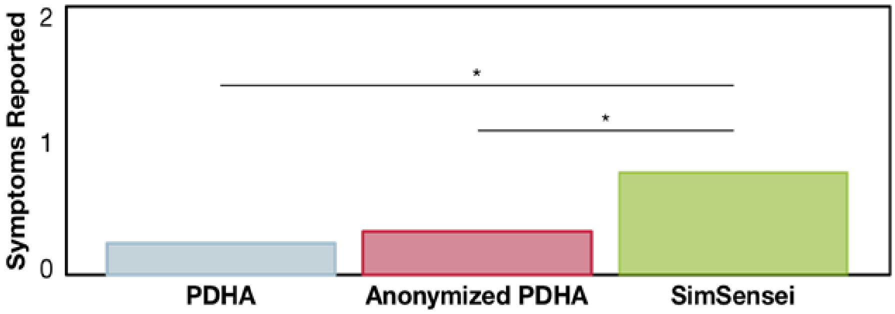

Figure 2. *Results of comparison between assessment types.*

Additionally, MultiSense facial expression analysis identified pre-to-post reductions in positive affect ($M = 0.32$, $SE = 0.05$ to $M = 0.15$, $SE = 0.02$, $F(1, 22) = 16.33$, $p = .001$) and increases in worry/fear ($M = 0.01$, $SE = 0.002$ to $M = 0.04$, $SE = 0.01$, $F(1, 22) = 8.41$, $p = .008$). This was in contrast to the self-report rating data that showed no difference in self-rated happiness ($M = 3.32$, $SE = 0.13$ to $M = 3.28$, $SE = 0.15$) and on the worry/fear rating ($M = 1.56$, $SE = 0.12$ to $M = 1.60$, $SE = 0.14$) pre- to post-deployment ($Fs < 0.11$, $ps > .74$).

4. CONCLUSIONS AND FUTURE WORK

The present study suggests that SMs following a deployment to Afghanistan were more likely to report symptoms of PTSD when interviewed by a VH than on both the official and anonymized versions of the PDHA. This result is in line with our previous work that indicated that users felt less concerned about being evaluated and displayed more sadness in an interview with a VH agent compared to one where they believed a VH avatar was being operated by a human-in-the-loop "Wizard of Oz" controller (Lucas et al., 2014). These results are part of a growing body of research that is suggesting that VH interviews may reduce hesitancy to disclose information (and hence, reduce the fear or experience of stigma) by providing a safe context where users may reveal more honest assessment information in contrast to situations where users are concerned about negative judgments on the part of a human assessors. Additionally, the automatic behavior detection involving facial expression provided a window into the emotional state that differs from self-report in the present study.

We are currently running a replication of this study with a larger sample of U.S. Veterans that aims to investigate whether these results can 1) be replicated, 2) be found within another military population, and 3) are not the product of confounds due to slight wording differences in the assessment questions between the questionnaire and the VH. Specifically, in this study with veterans, the wording is exactly the same across conditions. The data collection is ongoing, but initial results suggest replication and final results from that study will be presented at the conference.

The SimSensei interviewer is also being tested for its effectiveness as a PTSD assessment method within a clinical trial evaluating the use of virtual reality exposure therapy for PTSD due to Military Sexual Trauma. SimSensei interviews are being conducted at Pre-treatment, Mid-treatment, and at Post-Treatment. Data acquired from the capture and analysis of both verbal and non-verbal behavior emitted by the patients during the VH interview process is being compared/correlated with: 1) traditional self-report assessments (Clinician Administered PTSD Scale (CAPS) structured interview and screening measures of PTSD (PCL-M5) and other clinical measures (PHQ-9—Depression, etc.)), and 2) a learning theory-based psychophysiological "startle response" conditioning/extinction protocol. This will allow for a better understanding of the value of VH interview assessment in a situation where stigma due to the nature of sexual trauma may be high and thus, interview questions delivered by a VH may provide a safer context for honest reporting that better reflects the outcomes of treatment.

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

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Impact of the visual representation of the input device on driving performance in a power wheelchair simulator

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ABSTRACT

Virtual reality-based power wheelchair simulators can help potential users to be assessed and trained in a safe and controlled environment. Although now widely used and researched for several decades, many properties of virtual environments are still not yet fully understood. In this study, we evaluated the effects of the visual representation of the input device in a virtual power wheelchair simulator. We compared the virtual display of a standard gaming joystick with that of a proprietary power wheelchair joystick while users used either of the real world counterparts, and measured the effects on driving performance and experience. Four experimental conditions comprising two visual virtual input modalities and their two real counterparts as independent variables have been studied. The results of the study with 48 participants showed that the best performance was obtained for two of three performance indicators when a virtual representation of the PWC joystick was displayed, regardless of what type of joystick (real PWC or gaming joystick) was actually physically used. Despite not explicitly being made aware of by the experimenter, participants reported noticing the change in the visual representation of the joysticks during the experiment. This supports the theory that the effects of virtual reality representations have a significant impact on the user experience or performance, and visual properties need to be carefully selected. This is specifically important for applications where the transfer effects to real world scenarios is sought and ecological valid simulation is aimed for.

1. INTRODUCTION

Power wheelchairs (PWCs) can improve users' quality of life by enabling them to participate in daily living activities and decrease their dependence on human assistance (Lee, 2014). PWC users have to deal with restricted environments involving limited space to manoeuvre and are therefore vulnerable to collisions and injuries. Therefore, to use a PWC effectively and safely, individuals have to undertake training and an assessment of their competency. Swan et al. (1994) reported that: "the evaluation of user proficiency and the suitability of a given wheelchair is largely guesswork, and user training is limited to practice with a possibly unsuitable wheelchair". This has increased the need for better PWC simulations in order to train users to develop more expertise in driving PWCs and to assess user competency.

This has triggered researchers to investigate systems that could help to overcome the limitations of traditional PWC assessment and training. Already in the 1980s, Pronk et al. (1980) built a first system to help PWC users to adapt to actual PWCs. They concluded that such a simulation could help with the adaption and/or evaluation of PWC users. Subsequently more studies to evaluate the driving skills of PWC users were conducted. For example Cooper et al. (2005) measured completion time, number of path boundary violations, and errors between virtual PWC trajectory and desired path and concluded that such data could be useful in assessing and/or training PWC users. Moreover, they noted that a very important aspect of driving a PWC is the input device where the suitability can be objectively assessed through simulation. Previous research show several advantages of using a PWC simulator: potential utility as an assessment and/or training device, positive skills transfer from VEs to real environments, and objective measures of user performance easily generated by the simulator. These measures can be summarized as number of collisions either with objects or path boundaries, time spent, user trajectories, and combinations of these criteria to formulate a score.

Unfortunately there is a lack of commercially available PWC simulators outside of research that are appropriate for assessment and training (Abellard et al., 2010). Although commercial PWC software (WheelSim) exists, it is deemed unsuitable as a training and assessment system. In a usability inspection, Alshaer et al. (2013) detected severe shortcomings that make it unsuitable for use as a training and/or assessment system. Flaws identified by the authors were: 1) lack of an accurate physical simulation, 2) unknown size and driving speed of the PWC, and 3) inaccurate joystick interaction because the virtual PWC did not move and accelerate accordingly. Furthermore, pure software solutions still require the use of appropriate hardware as input devices which again could cause unwanted results if they are not specific to the software.

Building a realistic and effective virtual-reality-based environment requires the consideration of many factors. Two overview papers by Schuler et al. (2014, 2015) show that movement visualization, feedback and context information can have a significant impact on the user experience as well as on therapy outcomes for patients. This can also apply to virtual-reality-based vehicle simulators such as power wheelchair (PWC) simulators where correct physical simulation, realistic 3D modelling of the environment and the PWC, provision and/or simulation of the physical environment, and an appropriate interaction device may impact user experience and the functionality of the system. An essential hardware component of PWCs is usually a finger-operated joystick. Because actual PWC joysticks are proprietary and expensive, PWC simulators often use commercial gaming joysticks to interact with the simulator (Alshaer et al., 2013; Archambault et al., 2012) or adapted PWC joysticks (Hasdai et al. 1998; Adelola et al., 2002; Harrison et al. 2002).

Previous research has evaluated different input devices for different applications, either from a usability point of view, or in terms of performance. Rupp et al. (2015) report that the wrong input device: “can affect performance, increase cognitive workload and increase errors that may lead to the loss of a vehicle”. However, none of the previous PWC simulation studies have investigated the impact of using a PWC joystick compared to a gaming joystick. In fact, this also raises the question of the virtual representations of these input devices. According to Powell & Powell (2014), small changes in the virtual representation of the geometry of objects has an effect on the user experience and affects the perception of spatial location. This was demonstrated in their study where participants were asked to reach and grasp three different shapes in a VE (apple, sphere, and polyhedron) and measured the time participants took to reach the target. They found that users preformed significantly slower to locate and grasp a sphere compared to a polyhedron of the same size. This would indicate that the design of virtual objects, such as PWC components, could have a substantial effect on the performance of users and therefore influence the training and assessment outcomes in PWC simulations.

Our goal in this study is to evaluate the effects of the combination of virtual and real power wheelchair joysticks in the form of a proprietary power wheelchair joystick and a standard gaming joystick. Would one be perceived better than the other and therefore lead to better performance and experience? To our knowledge, this is the first study to investigate the visualization of the input device, in particular, if different input devices are used. In this study, we compared the virtual display of a standard gaming joystick and that of a proprietary power wheelchair joystick in combinations with their real world counterparts. The impact was assessed in the context of driving performance, where users’ path and wall collisions, and completion times were recorded as participants drove a simulated PWC. In addition, participants reported on their experience and awareness. This study aims to provide information to help designers/developers to create optimised PWC simulations and extend the knowledge on the effects of visual representation in VE on user performance.

2. METHOD

2.1 Participants

The study sample was recruited from people who attended the science festival at Otago University, New Zealand. We performed a statistical power analysis to estimate the required sample size before running the experiment. We used effect size from a similar previous experiment (Alshaer et al., 2013) to calculate the required sample size using the power analysis and the required sample size to detect differences was calculated to be 40. We recruited 48 participants (31 males, 17 females). Two participants data were not analysed, as they were the only two left-handed. The age range of the 48 participants was 18 to 73 years old, with a mean age of 34 (SD=11.97). Participants were also asked about their joystick experience before the experiment to determine how much information/training participants should receive before conducting the experiment. None of the participants were actual power wheelchair users.

2.2 Apparatus

Two aspects of the virtual reality (VR) simulation were considered: (1) the actual joystick, physically operated by the user, and (2) the virtual representation of the joystick within the virtual environment. Two popular joysticks were selected to be evaluated: a standard off-the-shelf gaming joystick (Logitech Attack 3) which is affordable and available in the gaming accessories market, and an expensive, purpose-built PWC joystick (Q-Logic control) which is used on many power wheelchairs and only works with PWC (Figure 1). Due to the specialist design of the PWC joystick, we modified it for use with USB input. To achieve this, an Arduino-based LeoStick (www.freetronics.com/products/leostick) board was electronically connected, programmed, and calibrated to read the PWC joystick outputs. These outputs were then mapped to function in the virtual environment. Hence, both the PWC and the gaming joystick worked the same for the user.

For the virtual joystick representations, realistic 3D designs for both the gaming joystick and the PWC joystick were modelled (see Figure 1). In addition, the physical movements of both joysticks were simulated. The 2 degree-of-freedom deflection of the joysticks were mimicked in the virtual representation in the VE. Therefore, pushing the joystick in any direction will immediately be visualized within the VE according to the participant’s movements. As with a real PWC, pushing the joystick further in any direction increases the speed of the virtual PWC and rotates the PWC in the direction pushed. None of the joysticks’ buttons were used in this experiment.

Figure 1. *Real PWC and gaming joysticks (left). Virtual PWC and gaming joysticks (right).*

Both joysticks were placed on a wooden frame so that the participant’s hand position was similar to that in a PWC (Figure 2). Both joysticks were connected to a laptop via USB. We used a 17″ Alienware high-end graphics laptop to run the simulator with a resolution of 1,920 × 1,080 pixels at 120Hz. Google SketchUp was used to design the 3D models, including the indoor environment (house), the virtual mid-wheel PWC, the virtual gaming and PWC joysticks, and the ideal path to be followed by our participants. Unity3D was used as the graphic engine platform for the simulation, which provides also the physics simulation capabilities.

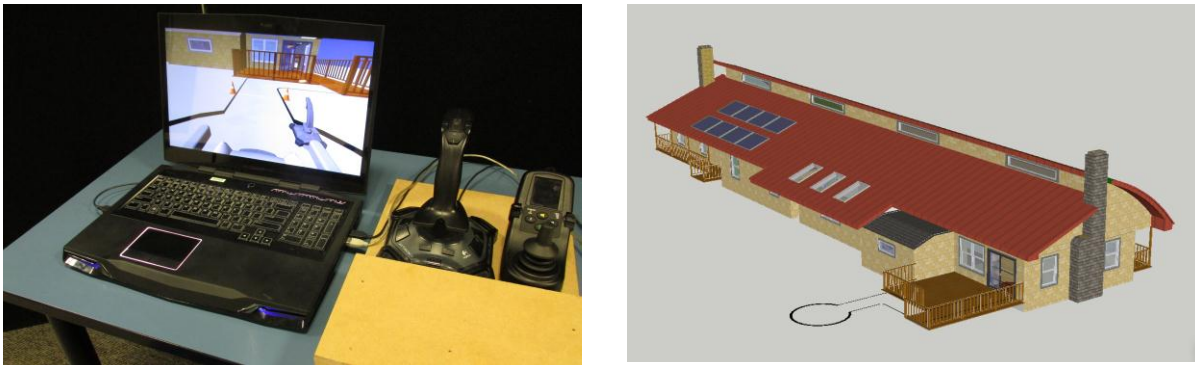

Figure 2. *(On the left) experiment setup: Alienware laptop, gaming joystick, and PWC joystick; (on the right) outside view of the house environment used in our simulation.*

2.3 Environments and Driving Task

A domestic environment (Figure 2) was used for the simulation. The environment was built to meet the Americans with Disabilities Act (ADA) (“Americans with Disabilities Act of 1990, as amended,” n.d.)‘ standards for accessible design. The effective width for internal doors accessed from corridors was 1.2 m and the

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corridor's minimum width was 1.5 m to facilitate 360° turning (Desmyter, Garvin, Lefèbvre, Stirano, & Vaturi, 2010). The user task was to drive as quickly and accurately as possible through this indoor environment by following an ideal path (driving between two black lines). The path was devised to contain most of the movements a PWC user would make in a domestic environment. These movements were inspired by the wheelchair skills test (WST). The WST is a set of assessment and training protocols developed by Dalhousie University (http://www.wheelchairskillsprogram.ca/eng/). Yellow arrows were placed on the path pointing in the direction of movement. The task (path following) was used in a previous study (Alshaer et al., 2013) and yielded a sufficiently variable performance.

2.4 Measures

For user performance, the following objective metrics were measured per condition: completion time, path boundary violations (when any of the PWC's wheels went beyond one of the black lines), and wall collisions. The overall performance score was calculated from the number of path boundary violations (pathViolations), the number of wall collisions (wallCollisions) and the total time in seconds (totalTime) required for the completion of the driving route using Eq. (1). The scoring system was used in (Alshaer et al., 2013), which was also inspired by Abellard et al. (2010), Hasdai et al. (1998), and WheelSim (2007).

$$\text{Score} = 1000 - (\text{pathViolations} + 2 \times \text{wallCollisions} + \text{totalTime}) \quad (1)$$

To measure user experience and awareness, we developed four questions consisting of seven-point Likert scale items where "-3" means "strongly disagree" and "3" means "strongly agree". The aim of these questions was to obtain participants' experience and therefore were asked once after completion of all conditions. The four questions were as follows:

- *Q1:* Overall, I felt as though I was operating the virtual joystick presented on the screen
- *Q2:* Overall, I felt as though I was operating the physical joystick in my hand
- *Q3:* Overall, I was aware of the switching between the virtual joysticks
- *Q4:* Overall, I was aware of the differences between the joystick on the screen and the one in my hand

2.5 Experiment Design

We used a 2 (physical joystick: PWC v Gaming) X 2 (virtual joystick: PWC v Gaming) within-subjects factorial design: the physical joystick handled by the participant (Attack 3 Gaming or Q-Logic Control PWC) and the virtual joystick represented on the screen (Attack 3 Gaming or Q-Logic Control PWC). This yielded four conditions as shown in Table 1.

Table 1. *2×2 factorial design.*

		Physical Joysticks	
		Gaming	PWC
Virtual Joysticks	Virtual Gaming	G-vG	P-vG
	Virtual PWC	G-vP	P-vP

2.6 Counterbalancing

Due to a potential learning effect associated with repeating of the task four times we controlled for ordering effects. First, subjects were randomized in counterbalanced order. Second, although subjects repeated the tasks four times, they were generally unaware of the repetition. The participants followed one layout on a return path, which created a balanced set of comparable paths that the user could traverse without interruption (Figure 4). The users couldn't really predict what was coming next, e.g. it was hard for them to know which direction to travel next as the right turn became left when driving in the reverse direction. In addition, the condition order set was randomized based on Latin Square counterbalancing.

2.7 Procedure

The experiment was run during a local science exhibition where participants, including school and university students, university staff, and the general public, came to participate in a wide range of scientific activities. All visitors were free to take part in any of the available activities. Upon arrival, participants were welcomed and consent was obtained electronically by clicking 'YES' if they wanted to be part of the experiment.

Participants were informed about the type of the virtual PWC (mid-wheel) and how it moved. They also received instructions on how to use the joystick and were given the opportunity to practice before starting the task. Once participants were ready to start, they were reminded of the task (driving as fast and accurately as possible). They were also told that they would be using two different joysticks and would see virtual counterpart representations in the VE. They were told to follow the ideal path, and stop if they saw a stop sign. Switching between virtual joysticks was done automatically through the simulator depending on the condition order set. When a stop sign appeared on the screen, participants were asked to switch between the physical joysticks. The stop sign appeared according to the condition order as well. At the end, participants were asked to fill in a demographic questionnaire and "overall" perception/awareness questionnaire (four questions).

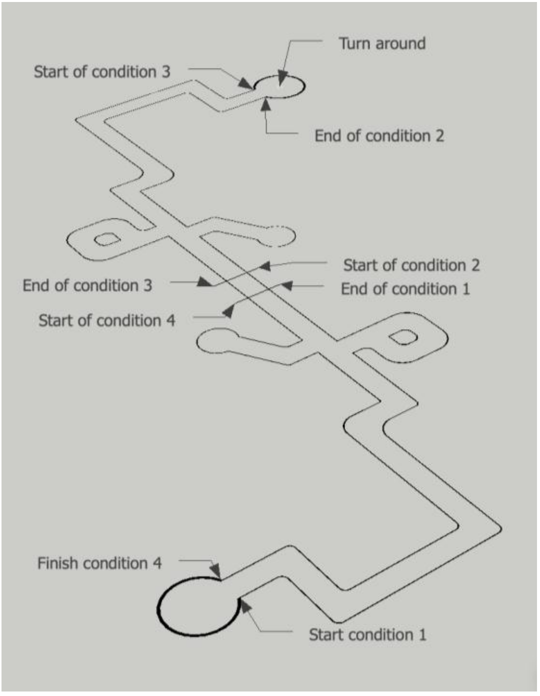

Figure 4. *Ideal path through the environment.*

3. RESULTS & DISCUSSION

3.1 Objective Metrics

*3.1.1 Path Boundary Violations.*The means of path boundary violations (driving beyond the black lines), together with standard deviations are reported in Table 2. A two-way, repeated-measures ANOVA was performed. The results showed that neither physical joysticks nor the interaction between physical and virtual joysticks had a significant main effect, but that virtual joysticks had a significant effect where participants had fewer path collisions when the virtual PWC joystick was represented ($F(1, 47) = 4.513$, $p < 0.039$, $\omega2 = 0.088$).

3.1.2 Wall Collisions. The means of wall collisions, together with standard deviations are reported in Table 2. A two-way, repeated-measures ANOVA was performed. The results indicated that the virtual joystick had a significant effect ($F(1, 47) = 7.009$, $p < 0.011$, $\omega2 = 0.130$) with participants performing better when the PWC virtual joystick was represented. Neither the physical joystick nor the interaction between the physical and virtual joystick had significant effects on the number of wall collisions.

3.1.3 Completion Time. The means of completion time, together with standard deviations are reported in Table 2. The time spent to complete the task was similar between each condition. Two-way, repeated-measures ANOVA was performed, but neither of the independent variables nor the interaction between them had significant effects on the participants' completion time.

3.1.4 Overall Driving Performance Score. The means of overall driving performance, together with standard deviations are reported in Table 2. The overall performance score was calculated with Equation 1 where a higher score indicated a better performance. A two-way, repeated-measures ANOVA was performed, but neither of the independent variables nor the interaction between them had significant effects on the participants' overall driving performance score.

Table 2. *Means and standard deviations for all objective metrics.*

Path boundary violations

		Physical Joystick Gaming	Physical Joystick PWC	
Virtual Joystick	Gaming	13.27 (9.75)	10.48 (.73)	11.88
	PWC	10.71 (7.81)	9.42 (8.43)	10.06
		11.99	9.94	

Wall collisions

		Physical Joystick Gaming	Physical Joystick PWC	
Virtual Joystick	Gaming	2.50 (2.24)	1.81 (2.09)	2.15
	PWC	1.65 (2.22)	1.65 (2.19)	1.65
		2.08	1.73	

Completion time

		Physical Joystick Gaming	Physical Joystick PWC	
Virtual Joystick	Gaming	57.35 (12.95)	58.42 (12.49)	57.89
	PWC	56.75 (14.18)	58.94 (14.32)	57.84
		57.05	58.68	

Overall driving performance score

		Physical Joystick Gaming	Physical Joystick PWC	
Virtual Joystick	Gaming	924.37 (19.68)	927.46 (18.75)	925.92
	PWC	929.24 (17.15)	928 (19.65)	928.62
		926.81	927.73	

3.2 Subjective Metrics

For the experience and awareness questions (Figure 5), a Wilcoxon signed rank test was performed against the midpoint (0) to see if the participants agreed or disagreed with the statements. Although participant answers to question 1 (“Overall, I felt as though I was operating the virtual joystick presented on the screen”) was slightly above the midpoint (M= 0.1, SD= 1.88), the one sample Wilcoxon test did not show a significant difference. On the other hand, the test showed a significant difference on question 2 (“Overall, I felt as though I was operating the physical joystick in my hand”, $p < 0.000$, with (M=2.15, SD = 1.11). A Wilcoxon Signed-Ranks test was performed to compare responses on the two questions. The analysis showed a significant main difference in favour of the physical joystick. Responses to both questions (Q3. “Overall, I was aware of the switching between the virtual joysticks” and Q4. “Overall, I was aware of the differences between the joystick on the screen and the one in my hand”) were above midpoint (M= 1.04, SD= 2.0, and M= 0.85, SD= 1.86 respectively). Both questions showed significant effects p= 0.002 for Q3, p = 0.003 for Q4. A Wilcoxon Signed-Ranks test was performed to compare responses on the two questions. There was no main difference between the two questions.

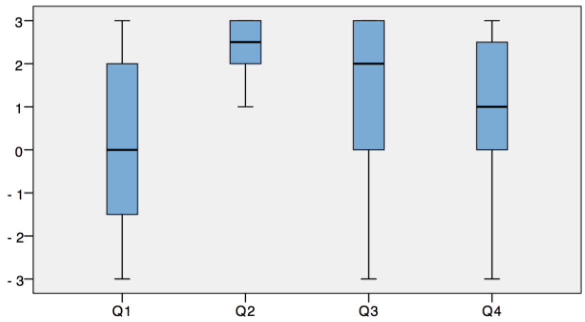

Figure 5. *Participants' answers to experience and awareness questions.*

4. CONCLUSIONS & FUTURE WORK

In this study, we evaluated the effects of visual representation of input devices in a virtual power wheelchair simulator. We compared the virtual display of a standard gaming joystick to a proprietary power wheelchair joystick while users used either of the real world counterparts. We measured the effects on driving performance and reported experience. Our results showed that for two of three performance metrics driving performance is significantly affected by the form of the virtual joysticks, but not by the type of physical joystick used. This indicates that performance can be influenced by changing visual properties, such as, the type of input device visualised. It also indicates that for the use in a virtual PWC simulator a rather inexpensive gaming joystick might be adequate.

The results of the study suggest that users of the simulator paid attention to the visual representation of the joystick and used it to guide their control of the PWC. We believe that the differences in the driving performance between the two virtual representations of the joystick is due to the level of how participants deduced steering information from the position of virtual joystick's handle. While the PWC joystick is equipped with a straight handle, the gaming joystick has a curved handle pointing forward on the top (Figure 1). This property of the gaming joystick could make it more difficult for participants to notice visual differences between small forward or backward positions of the handle and therefore impede the inclusion of this information in steering decisions; on the other hand, the properly aligned virtual joystick may help to enhance the participants' sense of alignment of the physical joystick. This might have led to better performance, in particular with novice participants. Another explanation could be that the virtual gaming joystick was an out-of-place distraction due to its size in the VE compared to the smaller virtual PWC joystick. Therefore, paying attention to the virtual game joystick degrades performance in a way that the PWC joystick does not.

Future studies may also investigate whether the effects were related to visual dominance theory (Posner, Nissen, & Klein, 1976), a felt sense of presence in the environment or both. The visual effect could be investigated more by tracking the user's eyes to determine when and how much time individuals would look directly at the virtual joystick. Moreover, the particular way in which we present the virtual joystick offers a convenient view of the input state near the centre of the display. A larger display could be used so that the physical joystick could be placed and viewed in the same relation to the virtual scene as the virtual joystick. Future studies could also investigate avatar-related conditions where the user's body or body parts are varied in their presence and visualisation characteristics. The participants used in this study were a convenience sample. This enabled us to meet the power requirements for the study. In addition, their unfamiliarity with PWCs and their proprietary joystick controller enhanced the internal validity of the study. The question of external validity or generalizability to the population of wheelchair users remains open for further investigation. Considerable variability in performance was evident between participants, so future studies might consider longer session times or repeated sessions and measures in combination with larger sample sizes.

Our findings suggest that visual properties of input devices represented in the virtual environment need to be carefully selected and chosen specifically for applications where the transfer effects to real world scenarios is sought and ecological valid simulation is aimed for. It also provides guidance on which VR input devices are necessary and appropriate and which virtual device representations can and should be implemented for power wheelchair simulators. In addition, with our simulator we have laid the foundations for a more comprehensive power wheelchair simulation system, including aspects of the use of simulator data to assess individual driving performance, correct physical simulation of power wheelchairs, and to take into account appropriate dimensions of an indoor environment to meet the standards for accessible design. This study provides an interesting test bed for future investigations.

Acknowledgements: The authors wish to thank all participants and the HCI group. Very special thanks goes to Chris Edwards for his help with the electronic modification of the PWC joystick and to Allied Medical Ltd. for providing the PWC joystick. The first author is sponsored by the Saudi Arabian Ministry of Education.

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Influence of navigation interaction technique on perception and behaviour in mobile virtual reality

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ABSTRACT

In recent years the development of affordable virtual reality has opened up enormous possibilities for virtual rehabilitation, and the introduction of ultra-low cost mobile VR such as Google Cardboard has real potential to put virtual rehabilitation right into patient’s homes. However, the limited interaction possibilities when a mobile phone is mounted into a headset mean that these devices are generally used for little more than passive viewing. In this paper we present an evaluation of three approaches to supporting navigation in mobile VR, and discuss some of the potential hazards and limitations.

1. INTRODUCTION

Until recently, Virtual Reality (VR) has been primarily the domain of experts in specialist laboratories. Whilst it has demonstrated great potential for rehabilitation, the high cost of the technology (Amer & Peralez, 2014) and technical knowledge required (Glegg et al., 2013) has created a barrier to uptake in many areas. However, in recent years there has been a paradigm shift in the accessibility of VR, with plummeting costs and increasing ease of use driving significant uptake at the consumer level. This opens up unprecedented opportunities for virtual rehabilitation, with the ability to deploy applications not only for use within clinical settings, but also directly into the homes of the patients.

This increased accessibility of VR inevitably presents new challenges for rehabilitation professionals, and in particular for those designing virtual rehabilitation applications. It is well established that interacting with VR can alter behaviour, and indeed, this is the very reason that VR has such potential for rehabilitation. However, it has previously been observed that increased availability of commercial off-the-shelf (COTS) games which involve physical interaction have led to an increase in physical injury amongst users (e.g., Bonis 2007), and it has also been demonstrated that there are a wide range of components within VR which may have an (unanticipated) effect on behaviour (Powell & Stevens, 2013). The rapid proliferation of consumer VR, without a clear understanding of how users will interact with these systems, may not only increase the risk of injury and adverse effects, but also deter future uptake of high quality virtual rehabilitation applications. Indeed, even leading consumer VR hardware suppliers recommend careful design in order to avoid unwanted side effects (Yao et al., 2014). This will become increasingly important as mobile phone technology improves, and in particular the processing and display of mobile graphics, leading to the emergence of this platform as a base for low cost virtual reality experiences (Steed & Julier, 2013).

2. BACKGROUND

The introduction in 2014 of the “Google Cardboard” virtual reality headset costing just a few dollars (Google, 2014), initiated a rapid proliferation of consumer VR applications, with over 1000 applications and 5 million users by January 2016 (Google, 2016). However, once the phone is mounted in the VR headset, the buttons and screen are generally no longer accessible to provide input to the applications, and control options are very limited. At the present time, they are used primarily for viewing 360 degree photos and videos, or for “passive entertainment” e.g. riding a virtual rollercoaster. The built-in accelerometers or gyroscopes included in most modern mobile phones offer a simple solution to basic tracking of head movement, allowing the user to look around in the virtual space. Active selection of objects can be achieved using head-orientation as a proxy for gaze direction, with extended fixation on an object triggering interaction (Sibert & Jacob, 2000). However,

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although active exploration is often not an option in mobile VR, the ability to navigate in a virtual environment should be one of the core tasks (Doug A. Bowman, Kruijff, LaViola, & Poupyrev, 2004), and for many cognitive and physical rehabilitation applications, the ability to navigate within the virtual space is essential.

Bowman (Doug A. Bowman et al., 2004) divides navigation tasks into the components of ‘way-finding’ and ‘travel’, and it is this latter component which presents particular challenges for mobile VR. At its core, travel involves the movement of the viewpoint within the virtual environment from one place to another. This movement can be instantaneous or it can involve both temporal and spatial components. The most natural way to travel in VR is to track the actual movements of the body. However, full body motion tracking is challenging (Slater, 2014), and this limits the possibilities for control of travel in low-cost mobile VR platforms.

Designing effective techniques for travel is not a problem unique to VR, and indeed there is a substantial body of Human Computer Interaction (HCI) research exploring navigation in 2D and 3D interfaces. However, the way in which VR is experienced is quite different to traditional interfaces, and we cannot assume that design guidelines from traditional HCI can be applied in the same way to VR (Jacob et al., 2008). VR interaction research is still in fairly early stages, and there is a lack of authoritative guidance regarding many aspects of design (Yao et al., 2014). Furthermore, different user populations may well have different interaction priorities, particularly where there is already cognitive or motor deficit. Designing VR applications based purely on intuition is driven by highly individual assumptions, and in order to select the most appropriate interaction technique for a specific population, it is important to first understand how it may impact cognitive load and behaviour.

Although in many ways the VR experience is very different from desktop 3D interaction, many of the underlying principles of virtual travel remain the same. An effective travel technique should promote appropriate velocity, spatial awareness, ease of learning, ease of use, a sense of presence in the environment, and the ability to gather information about the environment during travel (D. A. Bowman, Koller, & Hodges, 1997). Which of these elements are most important will depend on both the type of user and the nature of the task, and it could be argued that for physical rehabilitation, the motor response of the user to the interaction is also of key importance.

2.1 Travel techniques

In order to create a framework for evaluation of travel techniques in 3D environments, Bowman established a taxonomy to break the techniques into their core components, which he defines as “Direction selection” (specifying direction of travel), “Conditions of input” (requirements for starting or stopping travel), and “Velocity selection” (the ability to accelerate or change / reverse speed) (D. A. Bowman, Koller, & Hodges, 1997). In order to provide these components, it is necessary to mediate interaction between the user and the mobile application. For headset-mounted mobile phones such as Google Cardboard, there are three levels of possible interaction.

2.1.1 Phone-mediated interaction. Most mobile phones already have a number of in-built sensors, and it is possible to leverage these to allow some level of interaction. Accelerometers or gyroscopes are available on most Smartphones, and these can be used to detect movement of the phone, particularly changes in orientation. For mobile VR, head tracking generally relies on motion detected by these sensors, updating tilt and turn, although unable to detect translational movement (Sharma, 2015). In practice, this means that rotations of the head can be linked to the viewpoint of the virtual camera, allowing 360 degree viewing from a fixed point, but not directly supporting any movement through the environment. Whilst this is acceptable for experiencing fixed-viewpoint content such as 360^{o} photographs, it is not sufficient for exploration of a virtual environment. A common workaround seen in many applications is to use continuous motion, which is either constrained to a defined path (e.g. a rollercoaster or train ride), or allows free exploration within the bounds of a virtual environment, with travel being limited only by approaching fixed objects, such as walls, within the scene. With the latter technique, head orientation can be used to set the direction, with continuous motion which is effectively in the direction of gaze. This relates to ‘Direction selection’ in Bowman’s taxonomy, and this is the approach selected for the first of our three experimental conditions.

2.1.2 Headset-mediated interaction. Most of the ultra-low-cost VR headsets such as Google Cardboard have a sliding magnet affixed to the side of the headset. Movement of this magnet can be detected by the phone’s built-in magnetometer, allowing it to work as a proxy for a switch or button (Smus & Riederer, 2015). To date, applications using this magnet have focussed on its use for selection (e.g. choosing menu items), but it also has the potential to act as a “toggle” for initiating movement. This relates to the ‘Conditions of input’ in Bowman’s taxonomy. Our second experimental condition combines this movement toggle switch technique with the direction selection approach described in 2.1.1

2.1.3 Externally-mediated interaction. The primary appeal of mobile VR is its low-cost and portability. It has no need of any external equipment in order to provide at least an entry level VR experience. However, in order to widen the options for interaction, it may be necessary to add some additional input hardware. As far as possible, this should also meet the criteria of low-cost, portability and ease of use. A number of low-cost headsets come supplied with a small Bluetooth controller, offering the potential for direct control of motion via the mini joystick, and, as the input is analogue rather than digital, it can add an element of velocity control (albeit small due to the small range of input values which can be generated). This relates to the 'Velocity Selection' category in Bowman's taxonomy. For our third experimental condition we used the mini-joystick of the controller to directly control forward and backward motion, whilst retaining head orientation for selection of motion direction. It should be noted that we initially included the ability to strafe (left and right step) in the Bluetooth controls, but preliminary usability testing found that this seemed to trigger a strong feeling of disorientation and nausea. Furthermore, it is generally recommended to minimise the need for strafing within VR design (Yao et al., 2014), and so it was removed for this study.

2.2 Evaluating navigation techniques

Navigation is comprised of 'wayfinding', which is the cognitive process of determining a path, and 'travel', which is the control of the user's viewpoint motion within a Virtual Environment (D. A. Bowman et al., 1997). Navigation is not directly dependent on the specific interaction techniques, and thus is not the focus of this current study. Furthermore, the wayfinding component of a navigation task depends on a cognitive process which makes sense of visual cues and other aids within the virtual environment. It requires the acquisition of spatial knowledge, and this causes difficulties for some 20-30% of users (Sousa Santos et al., 2008), and can thus confound the results of an evaluation of travel techniques. Therefore, as far as possible, this confounder has been removed from the study by providing an opportunity to rehearse the navigation task, and by the use of verbal prompts to guide the users between target locations (section 3.3).

Travel is generally not an end in itself, but is necessary in order to move the user to important points within the environment. Moving within a virtual world involves both simple and complex manoeuvres, and both should be incorporated into any task designed to evaluate a navigation interface (Griffiths, Sharples, & Wilson, 2006). Simple manoeuvres should include cornering, 180^{o} rotation, forward movement on a straight line, and reversal of direction. Complex manoeuvres include moving around objects or through doorways, and moving towards a specific target location. All of these manoeuvres were combined into a structured navigation task.

3. METHODOLOGY

The three techniques to be evaluated were based on Bowman's taxonomy of travel techniques (Section 2.1), with increasing levels of control of the movement (Table 1). Although some authors recommend separating the viewing direction from the travel direction (Doug A. Bowman, McMahan, & Ragan, 2012), this necessitates an additional input in order to set a travel direction which is independent of the viewpoint orientation. As the goal of this study is to evaluate techniques using restricted input choices, we implemented travel in the direction of head orientation for all three of the travel techniques.

Table 1. *The three travel techniques evaluated in the study (counterbalanced order).*

Condition	Level of control (Mapping to Bowman's travel taxonomy)
Continuous motion	Can only control the direction ('Direction selection')
Magnetic switch	Travel can be stopped and started using toggle switch ('Input condition')
Bluetooth controller	Direct control of forward and backward travel ('Velocity selection')

The nature of the study requires a within-subjects repeated measures design. This inevitably introduces two factors which may contribute to an order effect. Firstly, increasing familiarity with the virtual environment may improve task performance and user preferences. The introduction of a rehearsal phase will reduce but not eliminate this effect. Secondly, any travel technique will be evaluated in the context of any previous technique, and with the continuous motion and switch techniques there may also be a learning effect of the travel technique itself. In order to minimise the impact of these order effects on the results, the study was designed as a counterbalanced study, with 6 different sequences of test order. Participants were sequentially assigned to the sequences in 3 blocks of 6.

In order to achieve a repeatable task which incorporated the required simple and complex tasks, a route was designed around a virtual flat, visiting six locations in sequence (Figure 1). The travel task involved forward motion, several 90^o and 180^o turns, reversing direction, manoeuvring around objects, passing in and out of two doorways, and planning routes to move towards target objects.

Figure 1. *The six target locations visited in the study in sequence from left to right, before returning to the starting location.*

3.1 Participants

Low-cost VR is designed to appeal to a wide range of the population, and so there was no specific target user group for this evaluation. Eighteen (18) participants were recruited from academic, support and administrative staff at the University of Portsmouth. There were 12 male and 6 female participants, ranging in age from 22-60 years old, with a mean age of 44, with a mix of background experience from VR enthusiasts to those who had never experienced VR before. Most of the participants were healthy adults, but one had moderate Parkinson's Disease (PD). Each volunteer was given a short introduction to the study and the three techniques to be evaluated, before giving their informed consent to proceed.

3.2 Equipment

A virtual flat was built in Autodesk 3D studio max and deployed in the Unity game engine, using the Google Cardboard virtual camera as the viewer. Models and textures were optimised for rendering on an Android phone, running at approximately 30 frames per second (fps). For each technique, the movement was set at the same (steady walking) speed of 1.5m/s. For the Bluetooth controller there was some scope for setting a lower velocity using the analogue joystick. In practice, the small size of the joystick and very small range of motion (+/- 2mm) meant that for all practical purposes it was always used at its maximum input value, equivalent to 1.5m/s.

The application was deployed as an Android Application Package (apk) file onto a Nexus 6 mobile phone, which was mounted inside a DeFairy VR headset. The controller used was a DeFairy mini Bluetooth controller, mapped to allow only forward and backward movement using the mini joystick. Participants were seated throughout the tasks on a swivel chair with armrests (Figure 2).

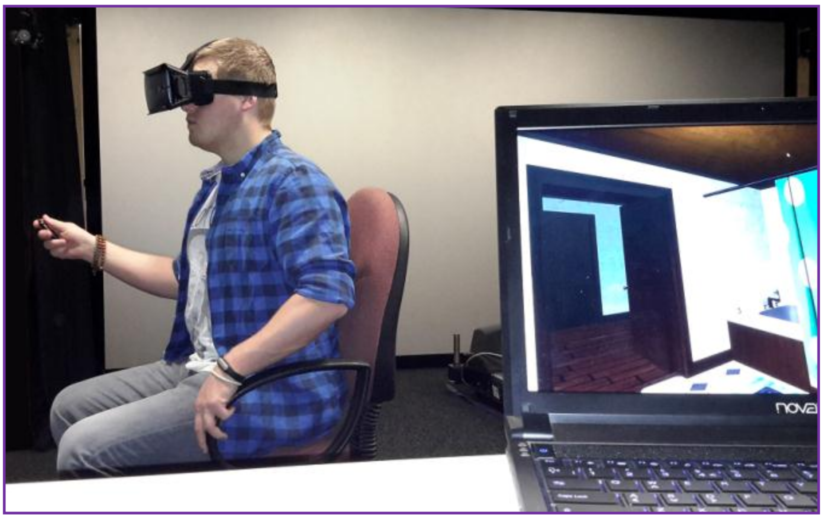

Figure 2. *The experimental setup.*

An operator view was mirrored in real-time on a standard PC laptop computer, and this was connected via a local wireless network to the mobile phone. This enabled the observer to track the progress of the participant throughout the task, and provide consistent and timely verbal prompts for each target location.

3.3 Procedure

Participants were briefed on the task and the techniques. They were then given an opportunity to rehearse the task and to familiarise themselves with the virtual environment, using keyboard controls and a laptop computer. Following the rehearsal, they completed the navigation task sequence using the VR headset three times, once for each travel technique, and answered a short series of questions after each trial. As the study did not involve memory or cognition testing, each time the participants reached a target location they were given a verbal prompt to direct them to the next location.

Each trial was timed from the start of movement until returning to the hallway at the end of the trial using a digital stopwatch on the operator PC. In order to record natural navigation behaviour, participants were not informed that they were being timed.

4. RESULTS

The three categories of observations recorded in the study will be discussed in separate sections. Quantitative analysis was carried out using IBM SPSS v22. Qualitiative analysis was carried out manually, categorising and coding the free-form text into themes which were then summarised.

4.1 Time to complete the navigation task

A repeated measures one-way ANOVA demonstrated a significant effect of travel technique on task completion time ($F_{2,17}$ F=10.00, $p<0.001$) (Figure 3). The mean completion time was fastest with the Bluetooth controller (50s), and slowest with the magnetic switch (85s). (Inclusion of the participant with PD disease (number 15) did not impact the results and so was retained in the analysis).

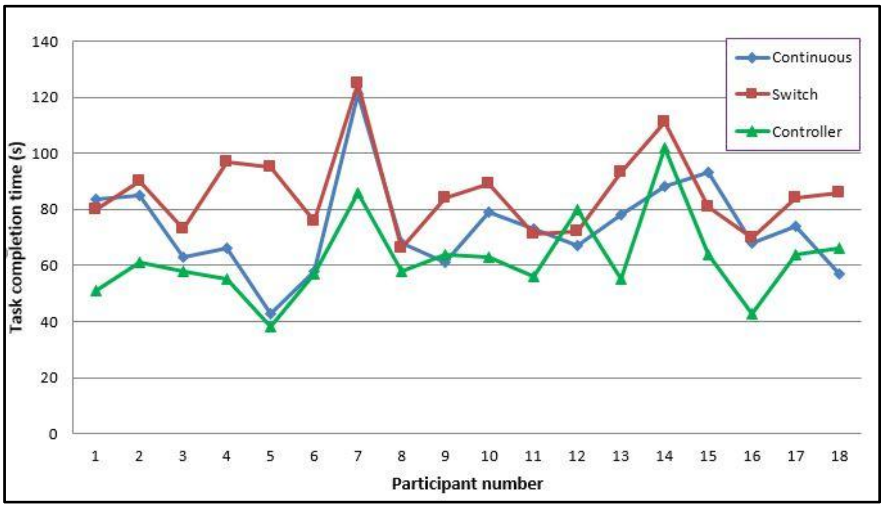

Figure 3 *Comparison of task completion times for the three travel techniques.*

4.2 User experience scores

Participants were asked three questions after each technique (Table 2). Each question was scored on a Likert scale from 1-5.

Table 2. *Mean Likert score for each question (StdDev in brackets)*

	Continuous	Switch	Controller
Ease of movement (1 = hard, 5 = easy)	3.3 (1.1)	3.8 (0.7)	4.5 (0.9)
Sense of presence (1 = unreal, 5 = real)	3.4 (0.8)	3.1 (0.7)	3.4 (0.7)
Liked the technique (1 = disliked, 5 = liked)	3.1 (1.1)	3.4 (0.9)	4.1 (1.1)

A repeated measures one-way ANOVA demonstrated a significant effect of travel technique on the participants perceived ease of use ($F_{2,17} = 8.41$, $p<0.01$) and on enjoyment of the technique ($F_{2,18} = 4.08$, $p<0.05$), but there was no significant effect of travel technique on the mini-presence score ($F_{2,17} = 0.90$, $p=0.41$).

Post-Hoc analysis revealed that the Bluetooth Controller was easier to use than both the continuous motion [t(17)=3.61, p=0.00.] and the switch [t(17)=3.01, p=0.01.], but there was no significant difference in ease of use between the switch and continuous motion. The controller was liked better than the continuous motion [t(17)=2.41, p=0.03.], but comparison with the switch, or between the switch and continuous, showed no significant difference.

There was a strong positive correlation between perceived ease of movement, and enjoyment of the technique (r= 0.78), and a moderate positive correlation between enjoyment and sense of presence (r = 0.38), but no correlation between perceived ease of use, and task completion times (r = -0.19). There was also a weak positive correlation between ease of use and sense of presence (r = 0.24).

At the end of the study, participants were asked to reflect on all three techniques and to compare them. The Bluetooth controller was the preferred travel technique, which was also expressed to be the easiest to use. The continuous motion was both the least liked travel technique, and the one that participants felt was hardest to use (Figure 4).

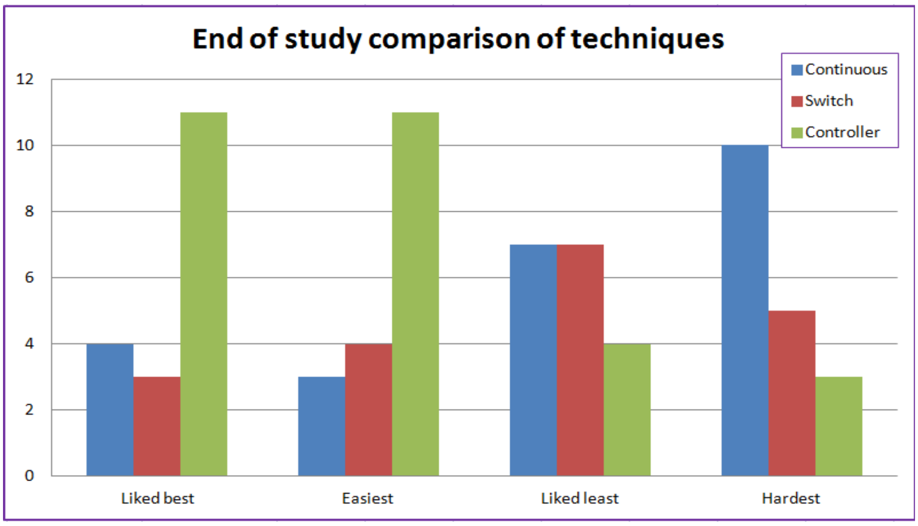

Figure 4. *Numbers of participants expressing preferences for each of the three techniques.*

4.3 Qualitative feedback

After each trial, and at the end of the study, participants were given an opportunity for additional comments on the travel techniques, and these comments were manually coded and categorised to identify common patterns or trends, as well as conflicting opinions. The majority of the responses fell into the broad categories of “control”, “discomfort”, “ease of use” and “naturalness”. Key points for each technique are summarised in individual sections below.

4.3.1 Continuous movement. With regards to control, 61% of participants expressed dissatisfaction with the lack of ability to slow down or stop. 17% stated that they used collision with obstacles in the environment to help them manoeuvre. In this condition, 39% of participants described some level of disorientation, generally associated with the inability to unlink head motion from the direction of movement, 22% of participants reported some level of dizziness or mild nausea when turning, particularly during sudden or rapid course corrections. For complex movements, 56% of participants highlighted the need to anticipate turns and plan ahead to ovoid overshooting the goals, but nevertheless, 50% of them explicitly reported that this condition was intuitive to use, with low cognitive demands and mapping of movement to head orientation freeing them up to plan the route without explicitly thinking about the controls.

4.3.2 Magnetic switch control. The qualitative feedback from this condition was the least consistent, but key factors emerged primarily around the location and responsiveness of the switch. 33% of participants felt that the switch gave them greater control over their movement, but others noted that on some occasions they either forgot to use it, or made a conscious decision to ignore it. The magnetic switch technique is known to have both false positives and false negatives (Smus & Riederer, 2015), and together with the small delay between sliding the magnet and the movement response caused 61% of participants to report dissatisfaction with the responsiveness of the control, leading to overshooting of targets and the need for error correction. The inability to control the speed or to reverse or sidestep was reported as a problem for 33% of the participants.

Nearly half of the participants expressed dissatisfaction with the location of the switch, with some feeling the need to hold the headset in place when using the switch, and reports of fatigue and aching in the arm due to prolonged elevation. The switch was felt to be a very unnatural way of controlling movement, with the distinctive sound, and the need to raise the hand to the head to stop or start motion being reported by 50% of participants as factors which diminished their sense of immersion or presence.

4.3.3 Bluetooth controller. The controller received considerable feedback, but much of it was conflicting. The level of control of movement was generally considered to be good, with 72% reporting that the controls were responsive, and that the ability to stop, start and reverse were important features. However, 40% of the participants described some level of mismatch between their expectations of the control and the actual experience. this mostly related either to the lack of strafing (right and left side steps), and to the need to use the head to control direction but the controller for speed. Some participants explicitly described this as making them have to consciously think about how to move around, however overall, 67% expressed satisfaction with the ease of use. 'Naturalness' was quite a polarised category, with positive comments generally relating to prior experience or intuitive use, and negative comments relating to less immersion, and to the mismatch between expectation and experience. Half of the participants felt that this was the least natural and intuitive way of moving around, even if they found it the easiest to use. Interestingly, the participant with Parkinson's Disease particularly liked this technique, and felt that it was less effort and offered "more control than I usually have with tasks".

4.4 Additional observations

Whilst there was no explicit remit in this study to record observational data, there were some recurrent behaviours worthy of note.

4.4.1 Movement of the body. There was a distinct difference in the body movements of almost all the participants depending on the technique in use. When using the handheld controller, they generally remained upright and fairly still, using their feet to turn the chair when changing direction, but otherwise showing little movement of the torso. In contrast, when using the other two techniques (and particularly the continuous motion), most participants involved the whole body in the interaction, tilting, turning and twisting the torso and leaning the head in response to anticipated changes in direction.

4.4.1 Frequent stopping. When using either of the controls which had the ability to stop the motion, many participants elected to stop movement for every change of direction, even in places where they had successfully manoeuvred in the continuous motion trial.

5. DISCUSSION

The performance and graphical fidelity of Google Cardboard techniques cannot compete with more expensive VR solutions, but it has the huge advantage of allowing the wider patient population to access truly mobile VR with minimal financial outlay. However, the quality and enjoyment of these first experiences could, for many patients, significantly influence their desire to engage with VR in the future. Furthermore, badly designed interactions may even hinder or undermine rehabilitation goals.

Whilst the findings of this preliminary work are based on a relatively small and heterogeneous group of participants and should be interpreted with caution, they do give some useful insight into the user experience, and offer some guidelines which may be useful to consider when designing mobile applications for virtual rehabilitation.

First and foremost, it is important to remember that we may have little control over the type of headset which is being used. The default position is likely therefore to involve continuous movement, perhaps mediated by head-orientation control or other software-mediated device. In this situation, any requirement to make tight turns or unplanned manoeuvres should be avoided, and a suitable collision boundary provided at points where the user may wish to stop. Whilst in ideal circumstances users should be provided with an independent line of site without changing direction (Doug A. Bowman et al., 2012; Sayers, Wilson, Myles, & McNeill, 2000), this may prove difficult when input options are limited.

The addition of the switch control to the continuous movement increased the time taken to complete the task without greatly improving the user experience, However, the current magnetic switches are not 100% reliable, and it may be that a more responsive switch might bridge the gap between the immersiveness of continuous movement and the ease of use of the handheld controller. With the recent release of Google's version 2 headset it will be interesting to evaluate whether the new capacitive switch will impact these findings. It was notable that this switch technique was significantly slower than the less controlled continuous motion. Whilst we might have anticipated fewer errors and corrections of direction, this did not seem to be the case, and, furthermore, most users chose to stop and turn at almost every location, even if they had previously navigated them smoothly using continuous motion. However, the unnatural position of the switch on the side of the head, and the implications this has for fatigue and pain, may make this unsuitable for many patient populations. This is of some concern, bearing in mind that a number of VR headsets currently being developed are planned to incorporate a number of headset-mounted controls.

Bluetooth controllers are available at very low cost, and indeed are often included with the purchase of a headset. For many users, particularly gamers, this provides a natural control, but it was reported to create a disconnect between the user and the virtual environment. However, this method was the most efficient for task performance, being nearly 50% faster than the magnetic switch control. This result is likely to vary with different navigation tasks, but is a significant factor, particularly where efficient maneuvering is required in an unfamiliar environment. When combined with head-orientation for direction selection, this technique appeared to have the highest cognitive load, and it may be necessary to use the controller for both direction selection and velocity control in order to lower the cognitive demands of this technique.

In contrast to reported immersion scores, we observed that the physical behaviour of the participants indicated a higher level of immersion when using the continuous controls than with the Bluetooth controller, and this warrants further investigation as it may have implications for certain types of application. Where increase immersion is desirable, for example in exposure therapy, then a hand-held controller may detract from this. However, the increase in movement of the torso and head, may increase the risk of injury or falls, and this is a significant consideration for many patient populations, particularly where there is already compromised balance.

In summary, none of the three techniques evaluated in this study offered an ideal solution for travel within mobile VR, but do point towards some preliminary design guidelines (Table 3). Further work in clinical population is necessary to establish more robust guidelines. In addition, in this study we only looked at task completion time in our objective measures, but for future work accuracy and error rate will be important additional considerations.

Table 3. *Preliminary usage indicators for the travel techniques evaluated in the study. The clinical indicators are tentative, as we have not yet tested directly in these populations.*

	Continuous movement	Switch on headset	Bluetooth controller
Accurate maneuvering	X	X	✓
Increase immersion	✓[1]	X	✓[1]
Balance impairment	X	X	✓
Parkinson's Disease	✓	X	✓
Cognitive impairment	✓[2]	✓	X
Avoid cybersickness	X	X	✓
Efficient travel time	✓	X	X

[1]Depends on individual user [2]for navigating wide or open areas

Acknowledgements: With thanks to Mark Silvester for his contributions to the virtual flat model, and to Dion Willis for assisting with data collection.

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Study of stressful gestural interactions: an approach for assessing their negative physical impacts

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ABSTRACT

Despite the advantages of gestural interactions, they involve several drawbacks. One major drawback is their negative physical impacts. To reduce them, it is important to go through a process of assessing risk factors to determine the interactions' level of acceptability and comfort so as to make them more ergonomic and less tiring. We propose a method for assessing the risk factors of gestures based on the methods of posture assessment in the workplace and the instructions given by various standards. The goal is to improve interaction in virtual environments and make it less stressful and more effortless.

1. INTRODUCTION

Gestural interactions allow users to manipulate a digital system using gestures, which can be compared to vocabulary for gestural interactions. Saffer (2008) defines a gesture as "any physical movement that a digital system can sense and respond to without the aid of a traditional pointing device such as a mouse or stylus. A wave, a head nod, a touch, a toe tap, and even a raised eyebrow can be a gesture." They differ from 'traditional' interactions (mouse or keyboard interactions, for instance) insofar as the latter do not consider the way in which the user performs the action. For example, the way in which the user presses a keyboard button does not matter: the only important thing is the fact that the button has been pressed, not the way of pressing it (Kurtenbach et al. 1990). In addition, more 'traditional' interactions provide a limited set of interactions depending on the structure of the input device (the number of buttons on a mouse, for instance) (Baudel, 1993; Isenberg and Hancock, 2012). Gestural interactions, on the other hand, allow users to take advantage of their whole body to interact with systems, therefore providing new interaction modalities and expanding the interaction vocabulary, resulting in a more flexible interface.

One of the purposes of gestural interactions is to facilitate interaction with virtual environments. They aim at being intuitive, easy to use and learn, since lots of them are based on the emulation of natural gestures (Rauterberg, 1999). Some can even fulfill specific needs, such as those of physically disabled people (Jégo et al, 2013). These interactions are supposed to entail less cognitive and physical effort than 'traditional' interactions: for example, the use of a mouse, which demands a physical effort because of its distance from the user, calls for the user's arm to be outstretched while requiring a very accurate gesture when pointing (Lalumière and Collinge, 1999). A well-thought gestural interaction could indeed solve those problems.

However, gestural interactions using movements requiring substantial physical effort can be associated with musculoskeletal disorders. What is more, the extended and/or frequent use of such systems can result in an overuse of the muscles in charge of performing expected gestures (Sparks et al, 2011).

There exist stressful, tiring, illogical gestures and some might be impossible to perform for certain people. For instance, interaction with some gestured-controlled TV sets is considered stressful (Freeman and Weissman, 1995) because of the high position of the hand during use. Interaction with touchscreens also affects user comfort negatively because of the need to keep one's arm outstretched (Lalumière and Collinge, 1999). The use of big screens is sometimes considered stressful to the neck because of frequent movements of the head and eyes (Bowman et al, 2006).

Few studies have been conducted on how to reduce the physical impact of gestural interactions on the human body and, as a result, non-ergonomic, stressful gestures that are difficult to use are often created, for want of guidelines (Aimaiti and Yan 2011). Interaction using such gestures can lead to various musculoskeletal injuries.

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To the goal of analyzing and assessing the health risks associated with gestures, we have studied task assessment methods in the workplace. Just like gestural interactions, those tasks consist of movements repeated frequently. In such assessment methods, physical impact of gestures is affected, for example, by the angle of the joint used in the gesture, the gesture's duration, its repetition, etc. The evaluation of those factors allows the assessment of gesture quality and consequently of their physical impact which, in turn, allows the design and implementation of ergonomic gestures that will cause neither pain nor stress, and which will be easier to use. We aim to implement a gesture assessment method based on certain criteria and factors stated in current studies.

In a first part, we present the medical problems related to gestures used in videogames and the workplace. The second part studies the existing assessment methods of physical movements. In the remaining parts, we propose a synthesis and an analysis of said methods as well as our own approach to assessing gestural interactions.

2. POTENTIAL NEGATIVE IMPACTS OF GESTURES

As mentioned previously (cf. Introduction), gestural interfaces are used more and more frequently in numerous domains. The use of such interfaces implies the performance of certain types of movements, sometimes repeatedly and/or for a long time, necessitating some effort. The overuse of the muscles in charge of these gestures can cause musculoskeletal disorders (MSDs). "The term MSD groups some fifteen diseases acknowledged as work-related pathologies. These pathologies represent more than 70% of known work-related pathologies" (Aptel et al, 2011). MSDs affect the muscles, tendons and nerves of upper and lower limbs, at the level of wrists, shoulders, elbows or knees.

A lot of MSDs have resulted from the frequent use of gestural interactions, such as those included with the Wii® gaming console (Jones and Hammig, 2009).

2.1 Painful gestures

Painful gestures are often caused by being subjected to an external or internal force and by exceeding the standard angle range at which joints are normally used. Those out-of-range angle values can be occasioned by numerous movements such as extension, flexion, abduction, adduction, pronation, etc. The movement range determines whether the joint is overly used and if the gestures resulting from the movement are potentially painful. Besides, static and dynamic constraints on some parts of the human body impact movement range and interdependence. (Nielsen et al, 2003; Eaton, 1997), for example adduction (moving a body part towards the median axis of the body), abduction (moving a body part outwards from the median axis), as well as pronation and supination, which designate limb rotations.

2.2 Injuries related to videogames based on gestural interactions

The repeated use of videogames can cause musculoskeletal injuries: for example, the use of the Wii® gaming console has occasioned sore muscles and knee, shoulder and heel injuries (DOMS: Delayed Onset Muscle Soreness) (Sparks et al, 2011).

Videogame-related injuries can be classified in four categories:

1. Tendinopathy: tendon injuries.
2. Bursite: swelling and irritation of one or several bursa.
3. Enthesitis: inflammation of the sites where tendons and ligaments are inserted into the bone.
4. Epicondylitis (tennis elbow): painful inflammation of the tendon on the outside of the elbow.

The main cause for such injuries and inflammations is the repeated stress undergone by involved muscles. According to the National Electronic Injury Surveillance System (NEISS), a high percentage of MSDs (67%) involve the use of Wii® in playing virtual sports (Jones and Hammig, 2009).

2.3 Work-related injuries

The movements used during gesture interactions are extremely similar to those performed in the completion of some work-related tasks at the level of repetitions, extended time span, involved muscles, postures and the force exerted (Sparks et al, 2011; Muse and Peres, 2011). These movements could occasion injuries called "Repetitive Strain Injuries" (RSIs). Several diseases have been associated with RSIs such as tendinitis, bursite, tenosynovitis, carpal tunnel syndrome, etc. (Simoneau et al, 1996). Symptoms such as pain, discomfort, and a sensation of localized fatigue in an overused joint can all point to RSIs.

The risk factors associated with the onset of RSIs and their level of severity depend on time span, frequency and intensity, and have been classified in six categories: awkward postures, force, effort and musculoskeletal load, static muscular work, exposure to certain physical stressors, repetition and the unvarying nature of the work, as well as organizational factors.

Effort depends on the joints involved, movement direction, posture and individual characteristics (Aptel et al, 2011).

In gestural interactions, most gestures are deemed natural (natural user interface) (Rauterberg, 1999), and require certain spatial movements, which in turn demand some effort as well as an internal or external force which can over-exert muscles and tendons affected by these activities (Sparks et al, 2011). Moreover, these movements are repetitive, and occur over a long time span (Aimaiti and Yan 2011). It is therefore possible to speculate that videogame- and work-related injuries are similar to those resulting from gestural interactions. It is rather clear that movements with extended arms, device vibrations and activities involving one's arm are very similar.

According to Nielsen (Nielsen et al, 2003) the basic principles of gesture ergonomics are: avoiding external positions, avoiding repetition, muscle rest, favoring neutral, relaxed positions, avoiding static positions as well as avoiding internal and external forces on joints and the interruption of the natural flow of bodily fluids.

3. GESTURE ASSESSMENT METHODS

It is crucial to find gesture assessment methods to devise gestures which do not lead to fatigue and health hazards.

3.1 Gesture assessment

The reduction of the negative physical impact of gestures requires an assessment procedure. This procedure would allow determining the level of comfort and the stress they cause by measuring risk factors related to said movements. Assessment methods are classified in two categories:

3.1.1 Subjective methods. Most studies on the assessment of the negative impact of gestures and physical movements in general resort to subjective methods (Nielsen et al, 2003; Muse and Peres, 2011). Amongst those, one can find:

- The Body Discomfort Diagram method (BDD), which assesses the level of discomfort in different parts of the body using a diagram of the body and an assessment scale. The diagram allows identifying and assessing the places and sources of discomfort by marking the affected areas (Cameron, 1996).
- Scoring methods, where a number of points is assigned to each single movement and criterion, resulting in a final score which determines the gesture's level of comfort. Each single score is decided either by the users (Nielsen et al, 2003) or by experts (ergonomists, etc.) (McAtamney and Corlett, 1993).
- Other methods are used, such as questionnaires (Ha et al, 2006), interviews, open-ended questions (Muse and Peres, 2011).

3.1.2 Objective methods and angle measurements. There exist methods and standards which allow the assessment of physical movements in a more objective way:

- *Electromyogram.* The electromyogram is a tool which measures muscle activity through the detection and recording of electric signals sent by muscle motor cells used during activity. The electric signal is amplified and processed to determine the level of muscle force exerted. (Long et al, 1970; Freivalds, 2004). This technique is used by Muse and Peres (2011) to measure muscle activity pertaining to the gestures and effort when interacting with touch-enabled devices.
- *RULA (Rapid Upper Limb Assessment).* RULA is a risk-factor assessment technique for upper limbs, geared towards individuals subjected to postures, forces and muscle loads potentially leading to MSDs (McAtamney and Corlett, 1993). The assessed factors are: number of movements, static work, force, work posture and working time.

  RULA allows the attribution of a final assessment score for each posture ranging from 1 to 7. This score indicates the level of discomfort for the posture: the higher the score, the higher the risk. It follows diagrams specifying the ranges of joint angles for various body parts. In these diagrams, a score is given to each movement depending on its angle (the farther the angle from a neutral position, the higher the score). This numbering system is also used to specify the level of force exerted as well as static and repetitive muscular activity. To calculate the scores, three score charts —defined by ergonomists— are used (McAtamney and Corlett, 1993).

The use of RULA is manual and the assessment is only possible for one side of the body at once (left or right).

- *The ISO 11226 standard.* The ISO 11226 standard (ISO, 2000) aims at assessing health hazards for workers involved in manual labor. The assessment process involves specifying and classifying posture conditions for each body part as acceptable or not. These conditions comprise joint angle, time-related aspects and movement repetition. The classification is based on experimental studies as well as the current knowledge in ergonomics.

  The assessment procedure is a one- or two-step process. The first step measures joint angles. If said angles do not exceed a given limit, the posture is deemed ‘acceptable’. If not, the second step focuses on the time span for which the posture is sustained. Extreme angles are never recommended. There exist several methods to recognize postures, such as observation, video, etc. Other factors are considered while assessing static postures, such as support (or its absence), sitting or standing position, etc.

- *The AFNOR NF EN 1005-4 standard (Safety of machinery – Human physical performance).* NF EN 1005-4 is an AFNOR standard (CEN, 1998) aiming to improve machine design in order to decrease health risks by avoiding postures and stressful movements leading to MSDs. This is done through the specification of various recommendations as well as a posture- and movement-related risks assessment method.

  It defines a posture and movement assessment procedure related to working with machinery. The assessment can either be ‘acceptable’, ‘acceptable under conditions’ or ‘unacceptable’. The assessed risk factors are: movement angle, gesture time, frequency, etc. In situations determined as ‘acceptable under conditions’, other risk factors must be considered, such as duration, repetition, period of recovery, the presence of a support to the body, etc.

In addition, some assessment methods for physical movements and some specifications for acceptability status for joint angles ranges were presented by ‘Institut National de Recherche et de Sécurité’ (INRS, National research and safety institute) (Aptel et al, 2000). Their objective was to better diagnose the work conditions in order to prevent musculoskeletal disorders.

3.2 *Creating non-stressful gestures*

Gesture creation by the user results in gestural interfaces taking user preferences and needs into account. Approaches to creating gestural interfaces are based on the concept of interface adaptability (Bobillier-Chaumon et al, 2005). One way is to use predefined (standard) gestures, where standard gestures are conceived from natural human gestures. A set of gesture vocabulary is derived by observing, collecting and assessing natural gestures performed by operators during scenarios (Nielsen et al, 2003; Ruiz et al, 2011; Wobbrock et al, 2009). The assessment is used to select the final gestures that will be used. Only few studies take physical factors into account during gesture assessment. Another way is to let the user define the gestures he wants to use in a preliminary step before starting to use the system (Jégo et al, 2013). However, the physical impact of the resulting gestures is not assessed.

4. DESIGNING AN ASSESSMENT METHOD FOR GESTURAL INTERACTIONS

We aim to design an assessment method for gestures used during interaction that would minimize their negative physical impacts. A complete gesture consists of a set of single gestures whose assessment results in an overall assessment of the gesture. The assessment of these gestures is done through the assessment of certain conditions and variables of the postures and physical movements effected. These conditions are: joint angles, posture duration, frequency, muscle load and external force.

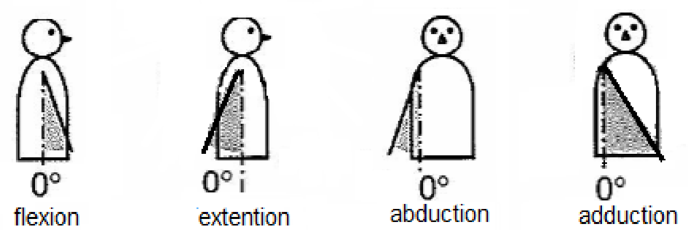

Figure 1. *Shoulder movements [Aptel et al, 2000], modified.*

Variables will be assessed based on specifications for acceptable and unacceptable movements in various studies and standards (CEN, 1998; ISO, 2000; Aptel et al, 2000; McAtamney and Corlett, 1993). These specifications assess movement variables, thereby evaluating the quality of the gesture.

Proc. 11th Intl Conf. Disability, Virtual Reality & Associated Technologies
Los Angeles, California, USA, 20–22 Sept. 2016
©2016 ICDVRAT; ISBN 978-0-7049-1547-3

The data related to each joint is organized in tables specifying all possible movement types for said joint and giving acceptable or unacceptable values for the various criteria and variables of movement. The angle of movement is a key factor in the assessment process, since it indicates the level of joint stress and, consequently, the potential discomfort to which that stress could lead.

The various levels of acceptability and comfort for shoulder movements (Figure 1) are shown in Table 1. In this table, the acceptability of postures and gestures is mainly determined with joint angles. What is more, gesture duration, movement frequency and other factors potentially affecting the level of comfort are assessed, such as supports for the body, an even distribution of weight on legs and feet, etc. Joint ranges are classified in ‘acceptable’, ‘acceptable under conditions’ or ‘unacceptable’ categories. The acceptability of movements is always connected to tasks with enough variation at the mental and physical levels (ISO, 2000). Similar tables for each joint have been compiled and are not printed here for want of space.

Table 1. *Recommendations for shoulder joint angles (CEN, 1998; ISO, 2000; Aptel et al, 2000; McAtamney and Corlett, 1993).*

Movement	Source	Acceptable limit (1)	Acceptable under conditions – Not recommended (2)	Unacceptable limit (3)
Antepulsion (Flexion- front)	AFNOR 1005-4	0° -20°	- 20° - 60° if static: (supported arm) or (short duration + recovery time) . - 20° - 60° if frequent. - 20° - 60° if: - frequency <10 per min - short duration - > 60° if short duration and not frequent	- > 60° if static - > 60° if frequent
	INRS	0° -20°	20°-60°	> 60°
	Tab Reg G			> 60°
	RULA	20° (1 pt)	20° - 45° (2 pts) 45°-90° (3pts)	> 90° (4 pts)
Retropulsion (Extension- back)	AFNOR 1005-4	0°	> 0° if : - not frequent - short duration	> 0° if static > 0° if frequent
	ISO 11226	0°		> 0°
	INRS	0°		> 0°
	RULA	0°-20°(1 pt)	> 20° (2 pts)	
Adduction	AFNOR 1005-4	0°	> 0° if : - not frequent - short duration	> 0° if static > 0° if frequent
	INRS	0°		> 0°
Abduction	AFNOR 1005-4	0° - 20°	- 20°-60° if static: (supported arm) or (short duration + recovery time) - 20° - 60° if not frequent. - 20° - 60° if: - frequency <10 par min - short duration - > 60° if short duration and not frequent	- > 60° if static - > 60° if frequent
	ISO 11226	20°	20°-60° (with support or check max time)	> 60°
	INRS	20°	60°	> 60°
	RULA	stressful (1 pt)		
Elevated shoulder	AFNOR 1005-4		stressful : if not frequent	stressful if frequent
	ISO 11226			stressful
	RULA	stressful (1 pt)		
Hyperadduction of the arm (with shoulder antepulsion)	ISO 11226			stressful
Extreme external rotation				
Arm support	RULA	- 1 pt		
Trunk leaning forward				

The measurement of time is crucial in the assessment of the acceptability of work postures: the longer the gesture and the higher number of repetitions, the more stressful the movement is. The different approaches use various strategies to measure time. Some measure movement frequency (repetition) (CEN, 1998; McAtamney and Corlett, 1993), others measure gesture duration (ISO, 2000), etc. Table 2 below shows ways of assessing time according to various approaches. In ISO 11226, the assessment of gesture duration is necessary when one gets a result that is ‘acceptable under conditions’. In that case, time is of the essence in the assessment process. The standard comprises graphs which plot the relationship between joint angle range and the maximum acceptable gesture duration. According to these curves, the movement is deemed acceptable if it does not exceed the maximum time (y) depending on the joint angle (x). The equations in Table 2 are calculated from these graphs (ISO, 2000; ISO, 2006). Some approaches use a scoring system based on an accumulation of points (McAtamney and Corlett, 1993; Nielsen et al, 2003). Besides, other approaches depend on joint angle testing followed by gesture duration to determine its acceptability (ISO, 2000). The information about the levels of acceptability of joint ranges, duration and other risk factors (such as repetition, force, muscle load, etc.) defined in various approaches are collected and organized so as to be used in the assessment process which aims to determine the level of acceptability of the gesture.

5. SOFTWARE STRUCTURE

5.1 Approach

Our goal was to develop a computer application that would allow detecting the conditions and variables of users' freeform empty-handed gestures, assess them, and determine their level of acceptability automatically according to various pre-existing methods and standards. The variables are mainly joint angles, duration, frequency, supports for the body, movement and posture style (weight distribution on both feet, rotation, etc.) This application could be used in the design phase of gestural interactions to decide which gestures are best. What is more, it could be used to assess pre-existing gestural interfaces and find out whether they are stressful.

Table 2. *Recommendations for the duration and frequency of movements. The application's inputs are: The physical movements detected by a Kinect device (which will probably be replaced by a more accurate device in the future).*

Inputs	Method
ISO11226 (ISO, 2000)	Trunk: for a leaning movement ranging between 20°- 60°, time acceptability is calculated with this equation: $y = -\frac{3}{40}x + \frac{11}{2}$
	Head: For a supported bowing movement ranging between 25°-85°, time acceptability y is: $y = -\frac{7}{60}x + \frac{131}{12}$
	Shoulder: For a supported abduction (elevation) ranging between 20°-60°, time acceptability y is: $y = -\frac{1}{20}x + 4$
RULA (McAtamney and Corlett, 1993)	Time is incorporated in the static load (calculate load versus time separately). Scores A or B is increased by 1 point if the posture is static Scores A or B is increased by 1 point if repeated (more than 4 times per minute).
AFNOR (CEN, 1998)	Movement repetition (if frequency >= twice per minute) Duration (according to ISO 11226).

5.2 Input

The application's inputs are:

- The physical movements detected by Kinect (which will probably be replaced by a more accurate device in the future). From the capture, we deduce:
  - angles
  - duration
  - repetition
- The presence of supports for the body and the possible presence of a rotation are manually entered for the time being.
- The tables of acceptable values for the following methods:
  - RULA

– ISO 11226
– AFNOR 1005-4
– INRS

5.3 *Outputs*

The application outputs results in a dialog box which includes:

- A binary assessment (acceptable or not) of the evaluated body posture, depending on the analysis through each approach we have implemented (RULA, INRS, ISO, AFNOR). Said assessment will only return 'acceptable' if the collected data is deemed 'acceptable' to each of the aforementioned standards and methods. We have adopted such an approach to ensure a maximum level of safety.
- In the case of a non-acceptable evaluation of the gesture, acceptability results broken down by body part will also be displayed, so as to easily locate the stressful areas which invalidated the assessed gesture.
- On the application interface, stressed joints will be colored in red in real time as shown in Figure .

5.4 *Architecture*

The application's design emphasizes clarity, modularity and revisability. It was indeed essential, when envisioning a basis which could be adapted to various uses and custom applications, that designers of gestural interactions could modify the software as they see fit without causing the whole program architecture to fall apart. It also makes potential evolution of test methods possible, following progress in the field or, in the case of a custom application, specific constraints or in-house assessment methods. It is thus very easy to modify or add tests to the aforementioned standards and objective methods included in the application. Furthermore, in the perspective of maximum safety, the software was designed to detect the maximum angles reached in the course of a gestural interaction, and it computes its assessments from these maximums, according to the standards and methods stated above.

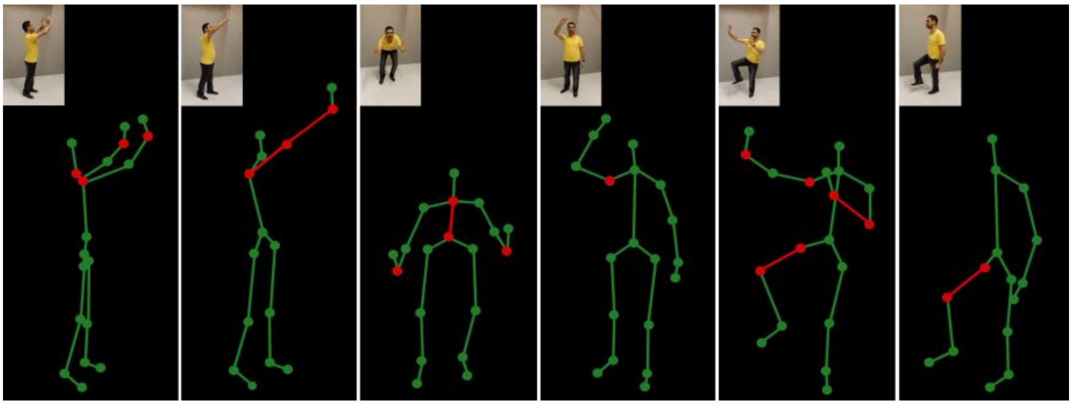

Figure 2. *Stressed joints, colored red in the application real-time output (simulated).*

6. PERSPECTIVES

6.1 *Assessment*

The goal of the assessment is to define less stressful standard gestural interactions. We will test a gestural interaction using certain joints (for instance shoulder, elbow, wrist, etc.) to decide on whether it is stressful. If it is, we will be able to point to the problematic joint(s) and the reasons for the stress (extreme angle, repetition, etc.) A subject will perform gestural interactions and the software will assess those gestures and display the assessment result (acceptable / unacceptable). It will also be possible to test several gestures and compare them to find the least stressful. We also collect additional subjective data from users to incorporate them into the assessment process for a better appreciation of user stress.

6.2 *Validation of the application (Method)*

We are aiming at validating our method through performing an experiment where subjects manipulate a gestural interface through performing certain tasks in different conditions. The application then evaluates the physical stress and gives results about the level of fatigue for each gesture and each joint. Furthermore, subjective results are collected from the subjects through a questionnaire about the level of the fatigue they felt in each condition and each joint. The results given by the subjects and those given by the application will be analyzed and compared to find whether they are correlated and by consequence whether the method is valid or not.

- Subjects. 26 potential users of virtual reality systems (students, museum visitors, videogame players, etc.).
- Tasks. We are currently developing several elementary and composite tasks to test our approach. For example, the tasks of selecting and moving an object, exploring a scene, etc. The first one is to arrange items, that is to select an object among several in the stock box, move and drop it in the corresponding box. Each task can be performed in different conditions (box height, number of times, time required, accuracy, etc.) Each subject is asked to arrange objects in various boxes using gestural interaction.
- Physical devices: Microsoft Kinect for Xbox® motion sensor and a computer screen showing the movements and assessment results.

6.3 Improving detection accuracy

We are for the moment using the Microsoft Kinect for Xbox® motion sensor to detect the movements. We plan to use more accurate movement detection techniques, such as a multi-Kinect system and / or an ART-Tracking movement detection system. We preferred using the Kinect device for his portability and usage facility (Zerpa et al 2015) .We are also thinking of using an EMG to detect the level of physical effort exerted, thereby making the method even more objective.

7. CONCLUSION & FUTURE WORK

In spite of the undeniable advantages of gestural interactions, the latter still exhibit several weaknesses, amongst which their negative physical impact on the subject performing them. In order to reduce that impact, it is important to implement a risk-factor assessment procedure to determine the levels of acceptability and comfort of the suggested gestures. This will ensure that the interactions created are more ergonomic and less stressful.

We propose a semi-objective assessment method of the gestures' risk factors based on the assessment of work-related tasks and the specifications found in certain standards.

Our objective is to try to improve interaction in virtual environments and make them easier and less detrimental to subjects. Moreover, our method may be used to assess physical movements in other fields, such as work posture, ergonomics or even physical therapy: the modular nature of our software makes it easily amendable —and, with some little work on the coding side, configurable— by the end-user. It is therefore feasible for a physical therapist in a context of rehabilitation, to change the default joint angle values (as well as other risk factors) provided in the software, taking some trauma into account, and then assess patient movement in real-time while avoiding unnecessary stress on traumatized joints.

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Open rehabilitation initiative: design and formative evaluation

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ABSTRACT

Development and testing of virtual environments for rehabilitation is a lengthy process which involves conceptualization, design, validation, proof concept testing and ultimately, if appropriate, randomized controlled trials. Ironically, once vetted, many of these VEs are not available to clinicians or their patients. To address the challenge of transferring research grade technology from the lab to the clinic the authors have created the Open Rehabilitation Initiative. It is an international independent online portal that aims to help clinicians, scientists, engineers, game developers and end-users to interact with and share virtual rehabilitation tools. In this paper, the conceptualization, development and formative evaluation testing are described. Three groups of developers of VEs (n=3), roboticists who use VEs for robot interactivity (n=10) and physical therapists (n=6) who are the clinicians end-users participated in the study. Interviews, focus groups and administration of the System Usability Scale (SUS) were used to assess acceptability. Data were collected on three aspects: 1) discussion of what a resource might look like; 2) interaction with the site; and 3) reaction to the proposed site and completion of the SUS. Interviews and focus groups were recorded and transcribed. Data from the SUS was analyzed using a One-way ANOVA. There was no significant difference by groups. However, the clinicians' mean score of 68 on the SUS was just at the acceptable level, while the developers and roboticists scored above 80. While all users agreed that the site was a tool that could promote collaboration and interaction between developers and users, each had different requirements for the design and use. Iterative development and discussion of scaling and sustaining the site is ongoing.

1. INTRODUCTION

Development testing of virtual environments (VEs) for rehabilitation is a lengthy process, which involves conceptualization, design, validation, proof concept testing and ultimately, if appropriate, randomized controlled trials. Often, once the technology has been developed and tested for a specific application, it is discarded. This results in a lack of transfer of the technology to the clinician at the point of care. Several explanations exist for the lack of transfer. One explanation is that the technology was not developed with the end-user in mind and therefore uses hardware that may not be readily available to persons in clinical practice. Another explanation is that the route to commercialization is expensive and lengthy and many scientists are not interested in pursuing this avenue. In this paper we propose the development of an international community as a solution, the Open Rehab Initiative (ORI), whereby developers may share their technology with clinicians.

As the virtual rehabilitation field evolves and technology becomes more accessible and available, the authors believe, it is increasingly important to find mechanisms to coordinate and bring together clinicians, scientists and engineers to interact with and share their efforts with virtual rehabilitation tools. Recent reviews support the use of virtual rehabilitation training in people with neurological diagnoses (Pietrzak et al., 2014; Laver et al., 2015). However, a large part of the implementation of VR in rehabilitation is limited to work developed in the context of research projects - which does not reach end users, in particular clinicians and patients. Currently what is available to clinicians are the results of efforts to repurpose commercial games available for game consoles by providing clinicians with tools to adapt the Wii™ (Deutsch et al., 2011) and online resources on how to use the Adventure Games for the Kinect™ (Levac et al., 2015). Resources are also made available by clinicians or researchers themselves through blogs or structured websites where hardware and software lists - mostly commercial Wii™ or Kinect™ games, and sometimes companies developing bespoke rehabilitation systems - are shared together with therapy game suggestions, ratings and tips (Leynse Harpold, 2016; Scott, 2016; TherapWii, 2016).

In implementation sciences, researchers have studied transfer knowledge as well as support of clinical reasoning by using online resources (Deutsch et al., 2015). The use of these resources for knowledge translation has been associated with positive behavior change in healthcare workers including nurses, physicians, physical therapists, and occupational therapists (Magrabi et al., 2004; McKenna et al., 2005; Grimshaw et al., 2006; Honeybourne et al., 2006). Unfortunately, less work can be found in the systematic transfer of virtual environments and serious games technology from developers to users. Multiple efforts exist in the creation of indices of games specially designed for specific health purposes (Lieberman et al., 2013; Serious Games Association, 2016). Unfortunately, available indices do not refer to literature specific to the applications and, consequently, the use of such games and applications is mostly not validated. On the other hand, other initiatives such as Games for Health and Games for Health Europe (van Rijswijk et al., 2016) feature a limited number of research projects with detailed descriptions and information regarding their target population and scientific outcome. However, in most cases content is unavailable to the clinician and end user. Consequently, there is still a large body of work on validated and research-driven technology that remains unavailable to clinicians and patient populations. There is therefore the need to facilitate the translation from research into daily clinical practice and to create new communication channels and a common framework to share and improve interventions in this area.

The ORI is an international independent initiative that aims to help clinicians, scientists, engineers, game developers and end-users to interact with and share virtual rehabilitation tools. The ORI portal is planned as a hub where the community who build and use software tools for virtual rehabilitation can easily communicate, interact with and share these tools. The webpage currently offers software, drivers, and documentation of evidence and application, with support for discussion boards, and blogs. Although ORI originates from academic institutions, it is designed to grow through community driven content, incorporating inputs from all the relevant communities. This sentiment is reflected in the ORI mission statement: ORI's mission is to become *"the go-to community for clinicians, scientists, engineers, game developers and end-users to interact with and share virtual rehabilitation tools"*. As such, we aim to attract both developers and virtual rehabilitation users, for research as well as for clinical practice. The scope of the simulations encompasses sensorimotor and cognitive rehabilitation.

The objective of this study was twofold: first, to describe the conceptualization and preliminary rendering of the ORI site; and second, to report on the formative evaluations conducted on three groups of users: clinicians in a rehabilitation setting, developers (clinician scientists and engineers) of VEs for rehabilitation and an engineering group that develops robotic devices that have serious game interfaces. As developers and roboticits have a certain degree of technical expertise and would be both contributors and users to the site, we anticipated that their assessment of the site capability as well as the usability ratings would differ from those of the clinicians.

2. METHODS

2.1 Overview

The ORI started as a multidisciplinary effort of the RiVERS Lab (Rutgers University, USA), the NeuroRehabLab (Madeira-ITI / University of Madeira, PT), and the Neurorehabilitation and Brain Research Group (i3B, Universitat Politècnica de València, SP). The conceptualization of the site originated with the founding members, to create the infrastructure, goals and a preliminary website. A user-centered formative evaluation informed the first iteration of the ORI (Usability Professionals' Association, 2016). Input was sought through user studies representing different communities that would be both contributors and users of the site. In this first iteration the person receiving therapy was not included.

2.2 Web design

ORI is a unified place to share and find all information related to the available applications (Figure 1). Applications are organized according to the following domain taxonomy: Upper Limb, Balance, Mobility, Cognition and Fitness, and their different purposes: Rehabilitation, Wellness or Assessment. Applications can be commercial/free, closed/open-source, but all have a contact person available for support and a dedicated forum available for inquires (Figure 2a). ORI currently hosts 3 different applications free of cost: the NTT for upper limb motor training (Bermúdez i Badia et al., 2012; Bermúdez i Badia et al., 2014), VSTEP for balance, mobility and fitness training (Gosine et al., 2015), and a posturography assessment instrument (Llorens et al., 2016). All applications in ORI are organized in a concise manner in a table characterized by their name, application domains, purposes, compatible hardware, software drivers, cost, and related publications as shown in Figure 2b.

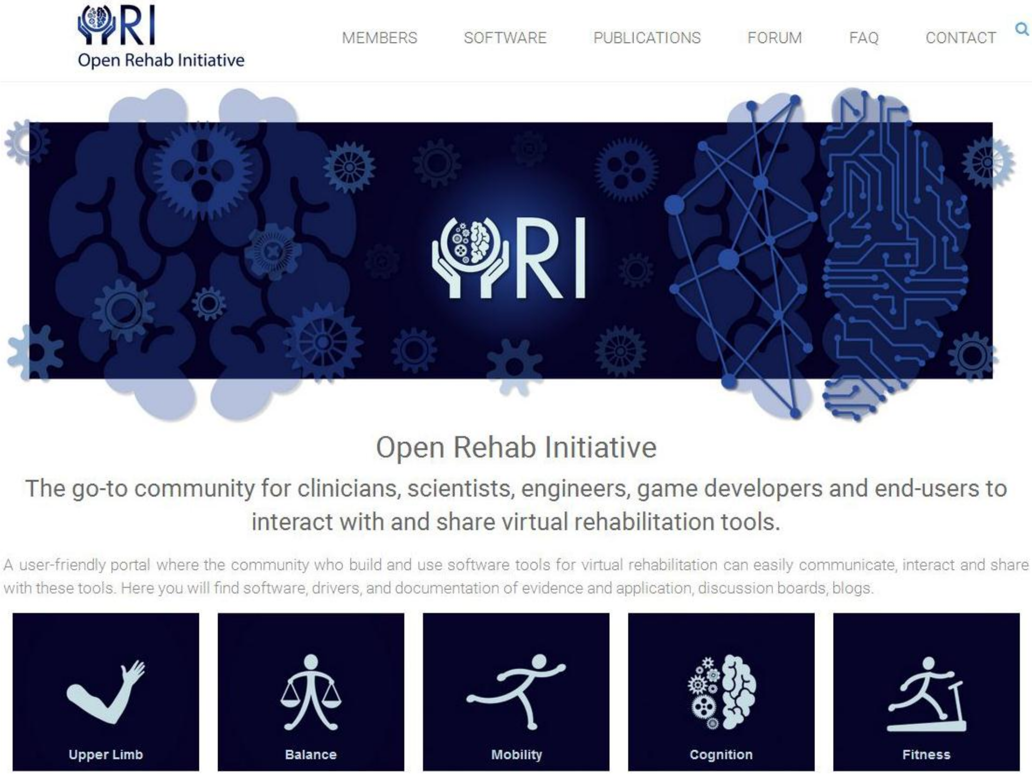
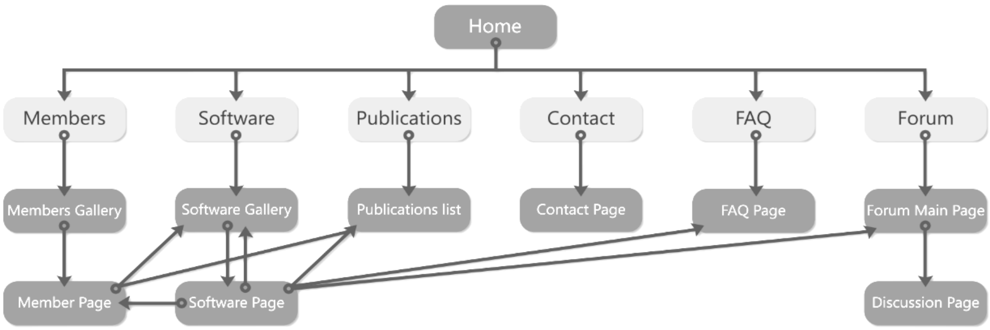


Figure 1. *The Open Rehab Initiative landing page. Content is organized according to the following taxonomy: Upper Limb, Balance, Mobility, Cognition and Fitness.*



a)

	Software	Domain	Purpose	Compatible Hardware	Compatible Software/Drivers	Cost	Publications
	NTT - Neurorehabilitation Training ToolKit	Upper Limb	Rehabilitation	AnTS, Keyboard, mouse, Kinect v1, Wiimote, mPower 1000, AR	Reh@Panel	Free	1, 2
	VSTEP - Stepping Game	Fitness, Balance, Mobility	Rehabilitation and wellness	Kinect v1		Free	1
	Posturography	Balance	Assessment	Wii Balance Board		Free	1

b)

Figure 2: *Open Rehab Initiative content: a) website structure and b) the first 3 initial applications.*

In addition to the table summary view, each application has a dedicated webpage where extended information is available about the application and its usage (Figure 3). The dedicated webpage contains a detailed description of the application with a video and/or several screenshots, detailed installation guidelines as well as requirements for its installation, license information and a link to the application in a downloadable format. A Frequently Asked Question (FAQ) section contains the most common questions and answers for each application. In addition, a forum enables further interaction with the application developers and other users of the community. All of this content is crosslinked in such a way that all information about each application is at most one click away from their dedicated page.

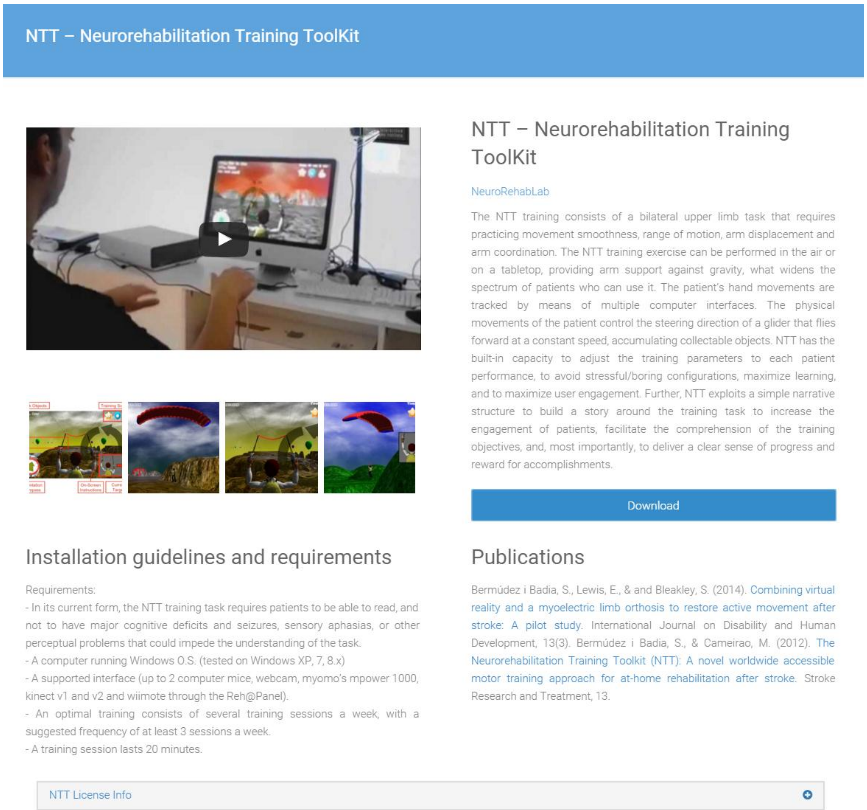


Figure 3: *Example webpage of the Neurorehabilitation Training Toolkit (NTT) featuring a description, installation guidelines, related publications, license information and link to the downloadable application.*

2.2 Participants

Three groups of participants were included in this study: clinicians (n=6), roboticists (n=10), and VE developers (n=3). The rationale for selecting the three groups was based on the anticipated diversity of users, namely those who may contribute to the site, such as developers in the field or persons in adjoining fields that use serious games (roboticists) and those who would use the technology, such as clinicians. Clinicians were recruited from the Servicio de Neurorrehabilitación y Daño Cerebral of NISA Hospital Valencia al Mar (Valencia, Spain). Participants in this group were 31.8±5.5 years old, had more than 2 years of experience in neurorehabilitation (11.3±5.5 years), and had a variable experience with virtual reality and serious games (4.3±4.0 years). Roboticists were recruited from the University of California Irvine (Irvine, CA, United States). They were high school, masters and PhD students, post-doctoral fellows and faculty. The majority were engineers. They ranged in age from 18 to 45 years. Developers included two engineers, who were recruited from Universitat Politècnica de València, and a clinician scientist, recruited from Rutgers University. They were 47.3±3.8 years old, and had more than 10 years of experience in the field.

2.3 Procedure

Data were collected in two formats: focus groups for the clinicians and roboticists and individual interviews with the VE developers. Both focus groups and interviews were divided in three parts. In the first part, participants were informed about the objective of the ORI webpage and then were asked what their desired features for such a site were. See the specific questions in (Table 1. Part A). Second, clinicians were given a case of a person post-stroke and freely reviewed the site to find applications to work with the patient. Developers and roboticists were asked to select one of the applications, look through it, and assess it for clarity, ease of use and implementation. Third, after 5-10 minutes of free use of the site, participants rated the usability of the system and completed the second part of the interview about their response to interaction with the website (Table 1. Part B)

Table 1. *Interview questions.*

Part	Focus groups - Clinicians and roboticists	Individual interviews - Developers
A	1. If you were to have a website where you could get video games or virtual environments for rehabilitation, what would it look like? 2. What would be the most important thing of it for you? 3. What features would you like 4. What information about the video games and virtual environments would you like to have? 5. Do you think the site should all be for free or would you be willing to pay for it? 6. Would you need technical support? 7. Would a discussion board be useful? 8. Would a Frequently Asked Questions section be useful?	1. Would your group participate in the initiative? Why or why not? 2. Would you share your video games or virtual environments for free? a. If yes, do you think the site should all be for free? b. If not, what would you want in exchange? 3. Right now what can you envision that your group would share? 4. If you were to contribute to this site. What instructions would you want to have in order to smoothly share your content? 5. What procedure would you use to populate the site with content? 6. What metrics on use would you find helpful? 7. Do you think this concept could increase the access to virtual reality and video games?
B	1. Do you think there is enough information to use it? If not, please specify what is missing. 2. What are the barriers to using this type of website in your practice setting? 3. What suggestions do you have for improving the site?	1. Please give us your input on the site. 2. Now that you have seen the site. Would you be interested in contributing to it? If not, please tell us why.

The usability of the system was assessed with the System Usability Scale (SUS) (Brooke, 2013). The SUS is a simple ten-item scale that serves as a global assessment of subjective usability. It employs a Likert scale with scores ranging from 0 to 100. Differences in usability scores between the three groups were assessed with a One-way analysis of variance. Statistical significance was set with an alpha of .05. Usability scores above 68 in the SUS questionnaire are considered to be above average (Brooke, 2013). Interview transcripts were reviewed and comments were summarized.

3. RESULTS

3.1 Desired features of the site

3.1.1 Clinicians. Their top request was simplicity of use, and considered accessibility and visual information as the most relevant factors to facilitate interaction with the site. Clinicians also reported that the site should categorize the software by relevant treatment areas (such as balance and upper limb use) to make searching easier. With regards to their clinical practice, clinicians would appreciate any information relating to indications and contraindications, dosage and average duration of treatment, as well as any scientific evidence of the efficacy of the software tools. Clinicians reported that the provision of videos of patients interacting with the video game or virtual environment would help them to understand the purpose of the training. They also suggested that the site should provide ratings both on the quality of the software (has it indications and contraindications, scientific evidence, a video demo, etc.?), and, on other clinicians' subjective impression of the software. In line with this, clinicians wanted a discussion board to share experiences and get feedback from their colleagues. Finally, clinicians reported a decreased self-efficacy with technology and indicated that they would require technical assistance to guarantee a successful use of the site.

3.1.2 Roboticists. This group's top request was that virtual environments be simple and allow multiple inputs. They wanted games or VEs to be played in a way that data would be collected and sent to the investigators. They preferred the code to be open source. They requested filter tags. As a criterion for uploading on the site, they suggested that a pool of reviewers test it and vet it. The criteria for keeping the games on the site would be based on the ratings of the clinician. They also wanted a section of the site to have open data that could be shared.

3.1.3 Developers. Engineers and a clinician scientist were willing to participate in the ORI to share clinically relevant simulations, to disseminate the results of their efforts, to find clinical population to validate their software or to run multicentre studies, and to learn about clinicians' needs as well as get feedback from clinicians on specific applications. Even though they were inclined to share their software for free, they drew attention to the fact that some VEs developed under the framework of public or private grants or projects could not be shared due to licensing issues. Engineers reported, on one side, that the site should make the use of the software very accessible and easy for clinicians, and pointed out that the site should provide user's manuals and technical documents with this purpose. On the other side, they were interested in knowing the number of downloads and, beyond this, the profiles of the users and their feedback as well as for which population the application had been selected. The clinician scientist felt there should be a minimal standard of reliability as the criteria for uploading content to the site. All the developers found the ORI website to be a promising way to increase the access to VEs for rehabilitation, were interested in sharing their software, and identified conferences and social media as the main actors to publicize it.

3.2 Reaction to the Site

3.2.1 Clinicians. Participants in this group reported that there was enough information to use the ORI webpage and identified four threats that could limit their use in the clinical practice: first, restricted internet access of some medical centers; second, unreasonable cost of the VEs or serious games; third, excessive advertising (banners, pop-ups, etc.) that would affect the usability of the site; and fourth, infrequent online content update. Finally, clinicians suggested that the site should prioritize any visual information.

3.2.2 Roboticists. Aside from very small bugs, they found the site very useful. They wanted a forum in which you could contact the author of the software. They were very interested in having the code available so there could be further development.

3.2.3 Developers. Developers highlighted the simplicity of the website and emphasized the responsiveness of the web site to provide an optimal viewing and interaction experience on all devices (desktops, tablets, phones, etc.). In this line, they pointed out that a larger font size would help to read some sections. The clinician scientist felt there was more information there that he needed, but he could filter it out. Some of the images had little contrast and were difficult to read. Finally, consistently with their reports before interacting with the website, they reported the importance of a discussion forum to contact clinicians and developers with each other. The clinician scientist reported that he associated the quality of the site with the investigators who had designed it. He revisited his point about the robustness of the application and the amount of testing it has as the criteria for uploading on the site. The idea of preferentially listing the applications that were free as well as including those for a cost appealed to him.

3.3 Usability Ratings

Developers and roboticist reported the highest scores (88.3±7.2 and 81.7±15.8, respectively), well above the suggested cut-off of 68, defining the webpage as acceptable in terms of usability. In contrast, clinicians rated the webpage with lower scores (68.7±5.8). Differences among groups were not statistical significant.

The mean scores of each group to the items of the SUS are shown in the Table 2.

Table 2. *Results of the three groups in each item of the SUS. Data are expressed in means.*

Users	SUS1	SUS2	SUS3	SUS4	SUS5	SUS6	SUS7	SUS8	SUS9	SUS10	Total
Clinicians	3	3	2.5	2.5	3	2.5	3	3	2	3	68.7
Roboticists	2	4	4	3	3	4	4	4	3	3	85
Developers – Clinician scientist	3	4	3	3	2	3	3	4	3	4	80
Developers – Engineers	4	4	3	4	3	4	3	4	4	4	92.5

3.4 Observations of Users' Interaction with the Site

3.4.1. Clinicians. This group found the upper limb application without any help. However, even though they were able to navigate the site, they repeated that some clinicians, especially if they are not used to serious games, might need assistance during the process. While using the site they also expressed that it would be useful to have information about "how many people are using each application".

3.4.2. Roboticists. This group immediately went to the heading software and selected an upper limb application. This is consistent with their area of work. When queried if they cared who had developed the site, their answer was no. They viewed the video before reading any sections of the text.

3.4.3 Developers. Engineers went through the posturography application and found the website "very simple to use" and considered all the information available "very valuable". After exploring other areas they showed suggested a re-organization of the areas. They suggested that if a there were many categories for the software on the site, that the classification be layered rather than showing them all at once. Specifically, one could have a main division between motor and cognitive applications, and then specific categories for each domain (upper limb, balance, etc. in the motor domain and attention, memory, etc. in the cognitive domain).

The clinician scientist found the upper limb application and watched the video. He was familiar with the application and the video and commented "I like this application". He did not feel he needed all the text. When encouraged to look at another simulation he found the posturography written descriptions to be very clear and commented "this would be very useful for a clinician". The images for this software were less clear.

4. CONCLUSIONS

As anticipated the three groups that were tested responded differently to the site although there was general agreement that the site would be worthwhile. The developers and roboticists had higher usability scores compared to the clinicians that just made the acceptability cut off.

Contributors to the site found that the site would be a powerful tool to overcome the gap between the development of virtual environments and serious games and their usage, and found the site usable with ratings of 80, above the satisfactory cut off rating. They were amenable to share their software and were equally comfortable with the software on the site being free or having a cost. Importantly, their desire to have feedback from the clinicians, not only about their use but also about their needs, and suggested the implementation of communication channels and forums for discussion. Importantly the contributors have indicated that they seek interactivity with the end-user as well as the other contributors.

Clinicians approved of the purpose of the initiative and showed interest in using the site. They, however, experienced a lack of self-confidence during the interaction, which may explain their lower usability scores. This decreased self-efficacy when clinicians interact with technology has been observed by others (de Joode et al., 2012). It is evident that the resource needs some revision and simplification to meet the needs of the clinician end-user. Clinicians offered specific suggestions to improve the site, such as: simple and clear explanations, prioritizing the use of visual information (videos, overall), adding tutorial and providing the technical assistance for unexperienced clinicians.

Given the initial approval by colleagues in and outside the field, the next logical step is to solicit input from the community of VR developers at our professional meetings, namely ICDVRAT and ICVR. It will be important to survey the community to determine who would be willing to contribute simulations and how would such a resource be implemented and funded. Thus, user feedback will inform the next iteration of the ORI site. Several important questions need to be addressed with regards to the acceptance of contributions: 1) what will the minimal requirements for eligibility to post on the site be? 2) How will the quality be rated? In addition, the acceptance of work-in-progress software, with dynamic and open-source contributions, and how to differentiate these applications from finalized software with stable and robust products for clinical use is still on debate. Our original intent was to support the clinician and thus we would require stable and robust products for clinical use. Alternatively, we can tag products in development to allow the end-user to shape the product. Future improvements of the site will also enable contributors and clinicians to leave their feedback. Perhaps we will require separate rating systems by clinicians and developers. Important decisions about balancing sustainability of the site and meeting the needs of the clinician as well as the developer have emerged from this study. These considerations will likely shape the future design of the site.

Acknowledgements: The authors wish to thank Teresa Paulino for the design and programming of the website, the staff of the Neurorehabilitation Unit of Hospital NISA Valencia al Mar and the Department of Biomedical Engineering at University of California Irvine for their involvement in the study. This study was funded in part by Ministerio de Economía y Competitividad of Spain (Project NeuroVR, TIN2013-44741-R and Project

REACT, TIN2014-61975-EXP), by Universitat Politècnica de València (Grant PAID-10-14), by the European Commission through the RehabNet project – Neuroscience Based Interactive Systems for Motor Rehabilitation – EC (303891 RehabNet FP7-PEOPLE-2011-CIG), and by the Fundação para a Ciência e Tecnologia through SFRH/BD/97117/2013 Projeto Estratégico – LA 9-2015-2016.

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Remote communication, examination and training in stroke, Parkinson's and COPD care: work in progress testing 3D camera and movement recognition technologies together with new patient centered ICT services

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ABSTRACT

This paper describes strategy and work in progress. The combination of patient centered care where many care and nursing units are collaborating with focus on, and in concordance with the patient, the ability to project information focused on the patient total situation and needs independent from where the information was created, the ability to use sensor technology to collect a wide range of aspects of the individuals health situation, the ability to use sensor technology to assess movements both for assessment and intervention purposes, to keep the care and nursing process together through module based information services and a structured care plan containing goals, sub goals, defined activity types and a wide range of health status data involving great opportunities for patients having chronic diseases. This group of patients causes extensive resource consumption for society. Well-structured data and semantic definition of data is a key for communication between different types of multi-professionals actors with different background. New technology, such as a wide range of sensor types, allows the possibly to capture large amounts of data both for assessment and intervention purposes in a continuous way over time. One example is how each planned patient activity has been performed and resulting health status aspects. This research group has worked on these issues for several years and some important milestones have been reached. From a chronic point of view three groups of patients are the focus: stroke patients, chronic obstructive pulmonary disease (COPD) patients and patients with Parkinson's disease. Collaboration approaches, communication technology and adapted information services allow new ways to perform home based care. Integrated monitoring services of planned activities like motion activities using 3D sensors allows professionals and patient to, in an exact way, follow planned and executed motion activities which are of great importance to many patient needs.

1. INTRODUCTION

A stroke or any other neurological disease/damage, like Parkinson´s disease, has profound impacts on a person's life. The conditions are often life long and require continuous treatment and rehabilitation, as well as support for the activities of daily life. Communication and the performance of assessment activities as well as intervention activities are tiresome and it is a challenge to create a care situation with continuity for the patient in order to achieve results. Due to the low physical mobility and poor overall condition of these patients, traveling back and forth to doctors, nurses and rehabilitation centres can be exhausting tasks. Communication and interaction with relatives and friends is important but often become cumbersome and may also include long, strenuous trips. More developed forms of home based care, in combination with support from various kinds of professional units, has great potential for innovation, with information technology as an enabler.

Rehabilitation is essential in order to promote and maintain maximal level of recovery by pushing the bounds of physical, emotional and cognitive impairments. It is the foundation to enable full reintegration into the society and pursued occupation. Assessment is a key component in the care of the neurological patient and important for

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both diagnostic and therapeutic purposes in clinical practice. Patients often perceive their experiences of rehabilitation care as non-connected or non-coherent over time. Continuity and early start for the patient regarding rehabilitation is important to reach constructive results.

For COPD patients the need and importance of performing exercise is similar. Performing exercise can aim at keeping existing capabilities of the individual and to contribute to the avoidance of exacerbation.

For many patients home based care can be an effective way to manage rehabilitation without being required to visit the hospital or other care unit when training has to be performed on a more daily basis. Video mediated remote strategies can be used to support and encourage the individual in being systematic regarding exercises for assessment and intervention purposes. Monitoring can be performed both by observing the individual, using video, but new possibilities are developed by using monitoring services which in detail can monitor how different movements have been performed using worked out representation approaches of sub-movements of each exercise type. Monitoring and storage of detailed results of each exercise instance can be used for feedback, visualization and analysis both for the patient and for the professional.

Stroke, Parkinson´s and COPD are examples of diagnoses where movements are of great importance both for assessment and intervention purposes and some exercises can be used for several diagnoses, but many types of exercises should be quite different depending on function resources and disabilities of the individual. For example, for stroke patients the rehabilitation service should allow exercises where differences between left and right parts of the body functions are focused.

In earlier work we have documented experiences of developing telemedical tools, tools for support of rehabilitation activities, including, sensor monitoring, 3D visualization and haptics (e.g. Pareto et al. (2011), Broeren et al. (2008), Goude et al. (2007)).

Experiences of this earlier work lead to the insight that:

1. Information services is needed to keep track of the whole set of relevant conditions and goals of the individual to be able to tailor personal plans which can encourage the individual to perform evidence based care activities
2. Be able to perform more of self managed care activities
3. Make it possible to add new types of sensors and to use the values for them in a structured way so that analysis and conclusions can be drawn related to accepted health condition types and classifications
4. Being able to point out affordable packages of equipment and services which can be affordable to most patients

Games are assumed to stimulate and reward a person, and to make it fun and engaging to perform serious activities. The aim is often and to reach results in terms of keeping up to a structured and individual exercise plan. If exercise activities can be performed through games a lot of encouraging effects can be made. A lot of development work is being performed to create a workable representation structure so that a good representation of exercise types (and its sub-movements) can be associated with one or several game type alternatives. The user can choose between different games for the purpose to perform certain types of evidence base exercises important for the individual.

For Parkinson's disease we are developing tools for remote assessment of motor function. The underlying scientific procedure is called Movement Disorder Society-Sponsored Revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS): Process, Format, and Clinometric Testing Plan (Goetz et al. (2008)).

Recent work is focusing on monitoring, visualization and assessment of how the planned execution of the exercises really was executed. A specific monitoring part of the services has been developed that monitors and stores how every movement has been performed. This monitoring sub-service used the body representation and body posture to describe how every moment has been performed. Further, we have showed that depth cameras and other types of sensors are useful to follow movements (e.g. prescribed exercises) overtime and can provide a measure of rehabilitation progress in a wide range of remote health monitoring. The objective of this investigation is to develop tools and knowledge to identify if new technology matched with patient oriented services and new care procedures will lead to better rehabilitation in terms of both cost-effectiveness and quality for the individual. The overall goal is a multi-purpose, configurable ICT service platform supporting home based care highlighting the individual patient's specific needs.

Related to monitoring, one type of monitoring can consist of automatic collection of data concerning for example how an exercise has been performed, one other important type of monitoring is self-assessment by the individual him-/herself. For example, to COPD it is of interest to collect data about how tiresome the performance of a particular exercise was experienced by the patient. For this purpose the Borg Scale can be used

(Borg (1982)). Borg scale assessments must be linked to the exercise performance and to the elements of the sub-movements.

2. MATERIAL & METHODS

3D sensors like the Kinect and other types of motion sensors like Leap Motion (LM) sensors are marker less motion capture systems which offer an attractive solution for home based rehabilitation. Although marker based tracking systems are more accurate, with spatial and temporal correspondence that marker less system lacks, the Kinect and LM devices' precision are sufficient enough for rehabilitation purposes (Fernández-Baena et al. (2012), Moeslund et al. (2006)). The devices' accessibility and low cost render them an advantageous solution for home based rehabilitation. The video game environment provided by the sensors has the potential to become powerful motivation tools for performing regularly rehabilitation exercises. Data from tracking the execution of the exercises in real time can be used for assessment of patients' physical status, which can trigger the need for interventions. Furthermore, captured data can be utilized to provide guidelines to the user, thereby optimizing the effect of the exercise.

A promising approach, explored in some depth for stroke and COPD patients, is to integrate support for video-mediated communication into the rehabilitation support platform, which includes both LM and Kinect devices. The Kinect device is in this situation used both as a body tracking device and a camera, while the LM device is used for tracking of hand and finger movements. A therapist/doctor can thereby remotely assist or instruct the home cared patient, in cases where direct physical interaction is not needed. Related to patients with Parkinson's disease their motor performance will remotely be registered with the Kinect and LM sensors connected to a laptop or tablet computer. During the fall of 2013 we implemented one of the MDS-UPDRS procedure, namely "alternating movements" and tested it interactively with doctors and patients. Here the patient is instructed to repeatedly approach and remove the thumb and the index finger from each others as much and as fast as possible. For COPD patients there are similar challenges. One of the challenges is the importance of keeping up training and movements and repeatedly meet health care professionals for plan change and updates and also to meet relatives and friends to avoid depressions etc.

For several diagnoses, the risk of falls is significant and structured fall prevention activities are hence important. Many of the tools and technologies explored for Stroke, Parkinson's and COPD patients can also be used for fall prevention. Assessment, risk calculation and intervention activities can be designed to reduce the risk of falls, which can be beneficial for many kinds of home care.

3. RESULTS

From our previous experiences of stroke rehabilitation, we know that 3D sensor based approaches like Kinect works well in an interactive situation in assessing kinematic information of motor function of the trunk, arm and leg. Now we have developed support for detection of hands and individual fingers. In most cases the interaction/instructions from the examiner can be pre-recorded ´machine´ standards. Our preliminary study of the MDS-UPDRS indicates a drawback, namely that some tests must comprise a physical interaction or/and an, at the actual moment, individualized instructions from the therapist/doctor. In these cases, we have to develop alternative procedures or omit these parts. An added value, as compared to the clinically performed MDS-UPDRS, is that with the ICT tools we can assess kinematic, numerical, values specifying the tested functions. Examples are frequency of tremor, time/velocity/acceleration/precision in movements.

Further findings are that one has to structure the entire set of subservices to really take advantage of the technology potentials which can be used in the home. Development and tests have shown that the following parts are suitable:

- A component that can, in depth, represent a particular exercise type often consisting of a set of sub-movements. This includes variation variables for individual adaptation (see below),
- A component that allows the therapist to define which movement a patient should perform, including definition of regime, intensity, repetition, sets and adapted movements. This is part of the individualization and needs and goals for the individual,
- A component that can monitor and store how the patient actually is performing each particular movement at each particular occasion,
- A component that can represent all relevant health condition types and classification related to a set of diagnoses, over all goals, sub goals, goal values of health condition types and relevant relationships to activity types.

- A video-mediated communication tool designed for communication between a professional and a patient where the professionals really can see how different movements are performed in each planned session,
- A component that can describe game types and how they are related to evidence based exercise types.
- A follow-up module where results of each training session are visualized related to goals. This includes more exact monitoring of how each movement is performed by each body part monitored in real time.

To capture, store and analyze large amounts of data about how all exercises have been performed, approached based on Big Data analytics will be used. When monitoring every training instance, e.g. for COPD patients, it can be very fruitful to monitor and store all training instances including sub-movements and also simultaneously monitor medical sensor data such as blood oxygen saturation levels when performing a particular exercise. Based on the collected data, assessments can be performed and conclusions can be drawn about how that patient should perform certain types of exercises, resulting in an updated care plan.

The following plot (Figure 1) shows the distance between the index finger and the thumb on the x-axis with respect to the relative speed between the two fingers on the y-axis. It shows an arc like concentration of dots which is what it typically looks like for a person without any disorder. The more a person is affected the more irregular and flat like are the plotted set of dots. This measure is an indicator of dysdiadochokinesia, the inability to perform rapid alternating movements, a sign of cerebellar and/or frontal cerebral lobe dysfunction. This kind of assessment can be accomplished by having the Leap Motion sensor attached to any home computer and having the patient simply surf to a web URL where the test can be carried out.

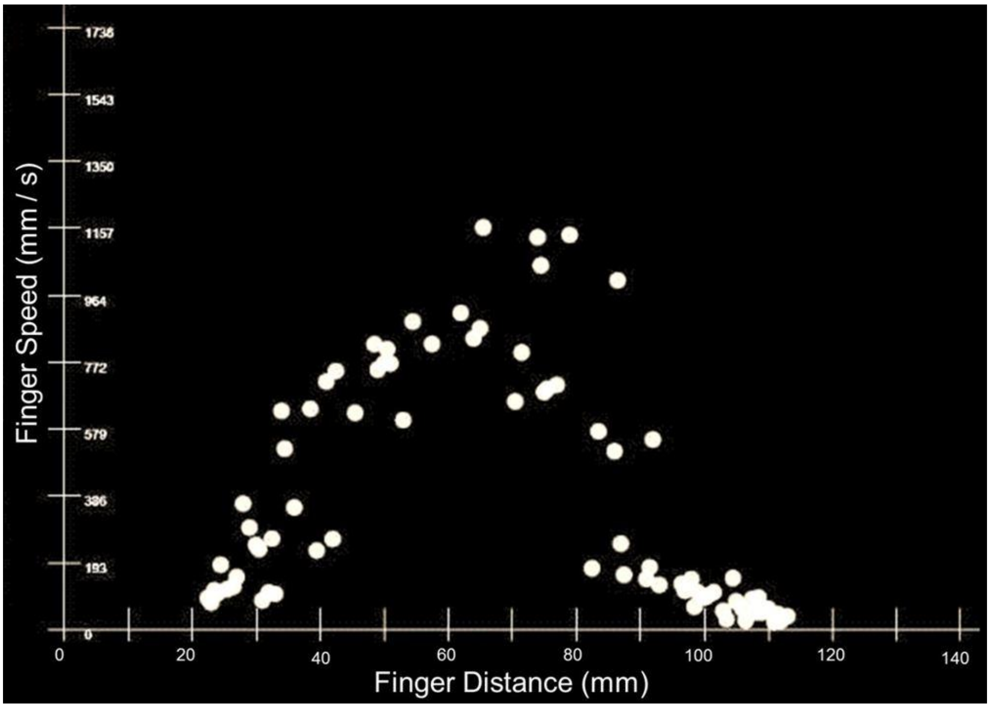

Figure 1. *The distance between the index finger and the thumb on the x-axis with respect to the relative speed between the two fingers on the y-axis.*

4. DISCUSSION

The work is in a development and exploration phase but soon more systematic comparative studies will be performed in order to measure effects. Fundamentally, the health cooperation concept is cross organizational process where different care and nursing units and actors can participate. The focus is the patient's overall situation and needs. All actors involved in different types of activities can access selected information in a distributed unit, based on the roles that they have related to the individual. The individual and relatives are heavily involved in the performance of the activities.

The platform architecture has two main parts: the service level and the sensor level. A large number of new sensors have been developed and new sensors will appear. Sensors are typically interpreted in relation to an assessment scale, reflecting a specific health care aspect. The service level is concerned with the logical process oriented interpretation, computation, visualization and storage of data. This architecture will continuously allow new technology to be adapted and integrated. All activities are structured into activity types and activity

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instances. Some activities are aimed at assessment of conditions and some activities are aimed at interventions related to goals (that change with time). The health plan is an important concept keeping all assessment activities, goals and intervention activities together. The plan can contain prevention as well as assessment and intervention activities.

In this patient/person centric approach, specific e-services, involving sensor technology, can be used for development of other movement oriented health assessment and intervention activities, like prevention of fall injuries and training of motor functions aimed at restoring muscle performance or breathing capacity. The e-services will contain subparts like definition of particular movement oriented activity types, support of how a particular activity instance should be executed, recognition of results of a particular activity instance, reporting of results of an activity instance, video-mediated communication with professional and other actors for support of a particular activity instance. For many activity types, including stroke assessment and rehabilitation, COPD rehabilitation and fall prevention activities, whole body tracking is the most important. For the UPDRS assessment activities, high precision finger tracking is also required.

The tool set outlined here can also contain tool parts supporting powerful assessment scales like the ICF scale. (The International Classification of Functioning, Disability and Health) (WHO) for the purpose of make an extensive analysis and assessment of the situation of the individual. This support can also contain support for setting of goal values related to ICF and the selection of activities for the individual.

5. CONCLUSIONS

Sensors, computers, displays and communication technology is getting better and cheaper enabling advanced e-services for home based care, including real time support from remote medical professionals. The developed solutions can be both cost effective and provide high quality for the patients, due to improved continuity of care, less need for travel, and improved motivation to perform physical activities more often. This means that e-health services for home based care, including communication with healthcare professionals, have a great potential to overcome the challenge with increasing demands of care due to an aging population. The services must support both asynchronous communication of patient data, as well as real time interactions for monitoring, assessment, and support. Not only health care personnel, but also relatives and other informal cares need to be included in the communication. By designing an ICT platform supporting both synchronous and asynchronous communication of data from tracking devices and other sensors, including depth cameras and video cameras, a flexible and configurable multi-purpose care solution for home cared patients can be developed. Until such a sophisticated platform is realized, however, experiments with enabling technologies in specific patient groups must be performed, which is the objective of our present study.

Acknowledgements: This project is partly supported by the Centre for Person-Centered Care at Gothenburg University and by VINNOVA, the Swedish Governmental Agency for Innovation Systems.

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Authenticating the subjective: a naturalistic case study of a high-usability electronic health record for virtual reality therapeutics

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ABSTRACT

Using data from our established Technology-Enhanced Multimodal Meditation (TEMM) stress-reduction program employing the electronic health record system Wellpad, we illustrate the value of developing a qualitative data-analysis approach to inform clinical practice in the rapidly emerging field of immersive therapeutics. In examining "rich data" of a naturalistic 50-patient TEMM cohort, indicates that, as with design of VR therapeutics, there is a highly salient role for immersive diagnostics, which ultimately relates to consumer satisfaction, both for patient and health-care practitioner.

1. INTRODUCTION

Following a rocky era over the past quarter century that industry pioneers might refer to as a multi-industry synergistic vision quest, we are now entering a new era of VR's impact on health and wellness (Durlach & Mavor, 1995). Overlapping with an industrialization of medicine and psychology into models embracing operational protocols, patient management models, and treatment guidelines, a need and opportunity currently exists for setting gold standards to inform clinical practice. In particular for evaluations exploring novel immersive or virtual reality therapy or rehabilitation tools, rather than understanding a patient's experience in terms of rote rating questionnaires, getting at the ultimate experience meaning of wellness and illness is called for at this juncture to optimize care planning.

Information systems are a key success factor for medical research and healthcare. Currently, most of these systems apply heterogeneous and proprietary data models, which impede data exchange and integrated data analysis for scientific purposes (Dugas et al, 2016). In this sense, we note the general problem for reporting of data related to VR mental health treatment and rehabilitation that a *lingua franca* of clinically relevant self-state descriptions and data-capturing that cuts across the wide variety of conditions and circumstances seen and treated in a psychiatry or psychology setting, whether these be anxiety, mood, trauma or organic brain disorders, including often co-occurring complex medical comorbidities such as disturbances of muskuloskeletal or sleep health. As we will discuss, this is of essence in being able to inform naturally occurring clinical realities beyond more artificially controlled academic or pre-clinical research studies.

What seems to be important is to arrive at a consensus regarding what "wellness" or "wellbeing" entail on a symptomatic/experiential level in a manner that cuts across rote DSM psychiatric classification categories. This is necessary due to the inherent heterogeneity of patients seeking wellness care. Additionally, finding mechanisms to creatively incentivize patients to offer up rich authentic data, whether though pre- and intra-session data (psychophysiological, gamified self-report, video capture, etc) makes for a more holistic evaluation potential that should be more fully entertained by clinicians and researchers. There is also the *Zeitgeist* of the "personalized medicine" era to consider. Personalized medicine research ie implies that on a clinical every individual patient is an individual "experiment", with unique circumstances and issues, bearing "rich/thick data", putting the VR industry in pole position to deliver authenticity beyond numbers.

Employing quantitative and qualitative considerations, we now report on our group's experience with ongoing development of Wellpad, an inclusively designed (Marti, 2012; Nussbaumer, 2001) and gamified (John, 2015) diagnostic electronic health record system intended to optimize the synergistic data flow in a busy operational medical setting.

2. METHODS

Drawing from a clinical database query of over 450 patients, a sample of 50 patients was identified who had completed between 7 and 15 scheduled TEMM sessions at the PRAXIS Holistic Health and Rosedale Wellness Centre relaxation hubs in Toronto, Canada before February 14, 2016. These consenting participants resided within the Greater Toronto Area (GTA), the furthest participant being located an hour away from the health centres.

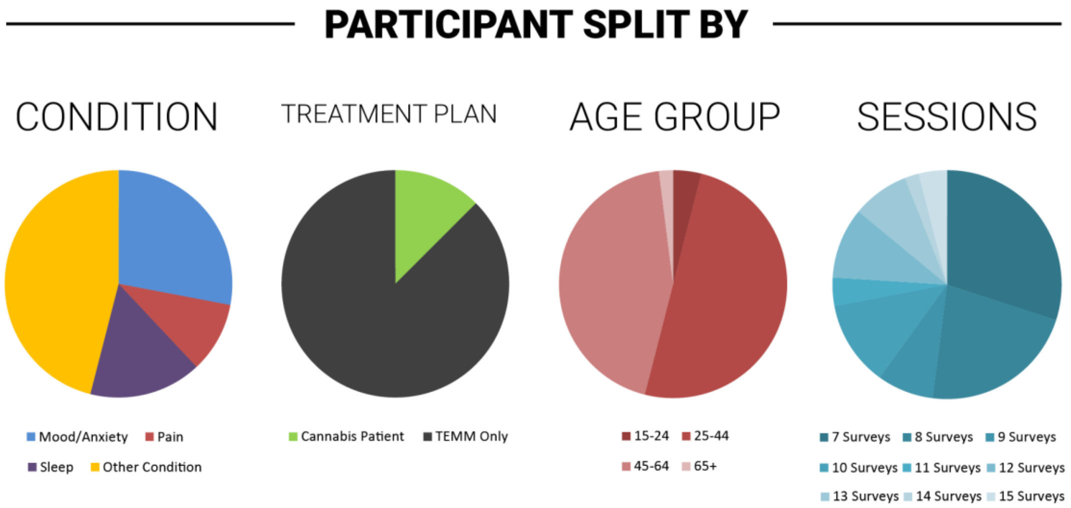

Figure 1. *Various proportional classifications of the 50-patient sample.*

2.1 *Easy Data Collection Protocol*

Keeping a simple Electronic Health Record of participants, VR practitioners can create personalized wellbeing experiences responsive to the needs and motivations of the modern leisure-seeking consumer. Knowing the balance of demographics like condition, current treatments, age, and length of treatment among a user sample as in Figure 1 is a key driver for praxis by feeding real world results back into the development of more effective new immersive therapeutic programs.

After participant suitability for TEMM is authenticated and she completes a brief intake survey, baseline 1-5 likert scores for relaxation, pain, sleep quality, and energy in recent times are captured by the inclusively designed iPad-based Wellpad EHR system. Popular medically supervised meditation programs like "Creative Problem Solving" and "Balancing Your Moods" are delivered to the patient via non-invasive synthetically packaged leisure-state meditation experiences with relaxing visual, auditory and haptic channels in chair and bed delivery systems (Moller & Bal, 2013).

2.2 *Holistic Diagnostic Progress Tracking*

Progress tracking with Wellpad at PRAXIS Holistic Health and Rosedale Wellness Centre currently focuses on a longitudinal visualization of wellbeing captured before each weekly TEMM session. The patient's 1-5 score for each attribute in recent time and potentially significant patient comment/context are plotted visually as seen in Figure 2 and reviewed with physician during the consultation. The utility of this narrative cue for inclusively exploring the experience user's health over time has been demonstrated before (Moller & Saynor, 2014; Moller et al, 2015) and will be expanded upon by adding followup surveys directly after the treatment session.

The 5 attribute scores for each survey submission are averaged into a general Wellness Score, which is readily stacked with peers to identify broader trends. For instance, Figure 3 shows a maximalist 50-patient spectrum of self-reported wellbeing over time, which can also be averaged across the group (Figure 4) or split by question average (Figure 5) to check for trends among disparate patients or very specific groups.

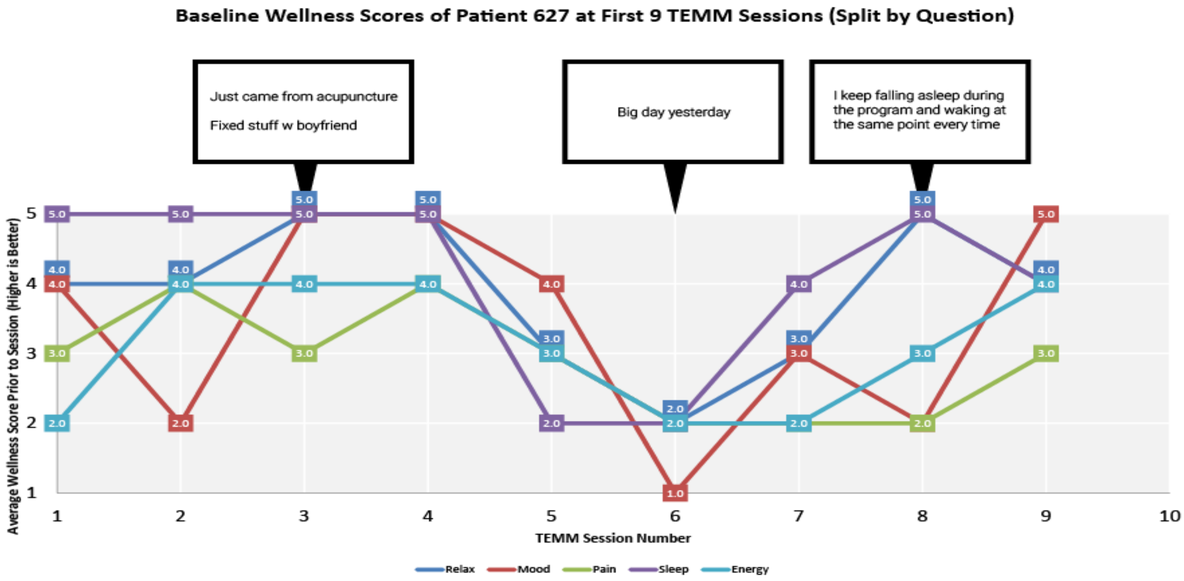

Figure 2. *One Stress/Anxiety patient's wellbeing over time while undergoing TEMM treatment. The plunge before the participant's 6th session suggests the patient may need extra attention*

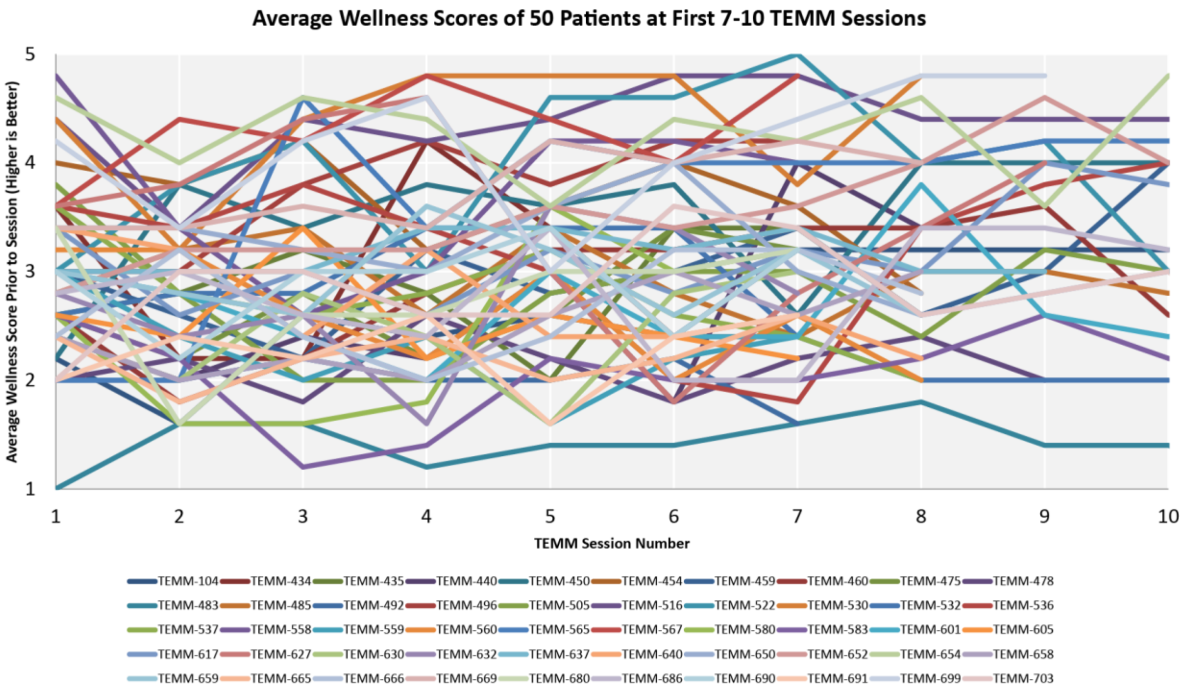

Figure 3. *50-Patient spectrum of average patient wellbeing over time may reveal broader trends.*

Section 2.3 Exploring the Future Potential of Rich Data

While we believe in evidence-based approaches, evidence does not necessarily consist of structured data points. In VR research, we believe that the life experiences need to be accounted for to derive optimal knowledge. This is particularly true when studying mental health and the complexity of changes in consciousness common in stress and anxiety patients.

This notion feeds into the multimodal nature of the immersive therapies used at our health centre and others endeavouring immersive/VR therapies; we advocate for a further future promotion of multimodal diagnostic data-gathering, which has already been embraced for some time by VR researchers in the form of psychophysiologic (EEG, galvanic skin conductance, EKG heart rate variability, polysomnography etc.) monitoring, eye-movement or blink tracking, motion capture and psychomotor performance tracking inherent to gamified therapeutics. Now that the mobile technology industry is experiencing a commercial proliferation of health and wellness devices and aps (e.g. smart watches, fitness- and brainwave-trackers), we are learning about consumer acceptance, tastes and preferences of what aspects of their daily experiences we can authentically capture to better understand patient wellbeing.

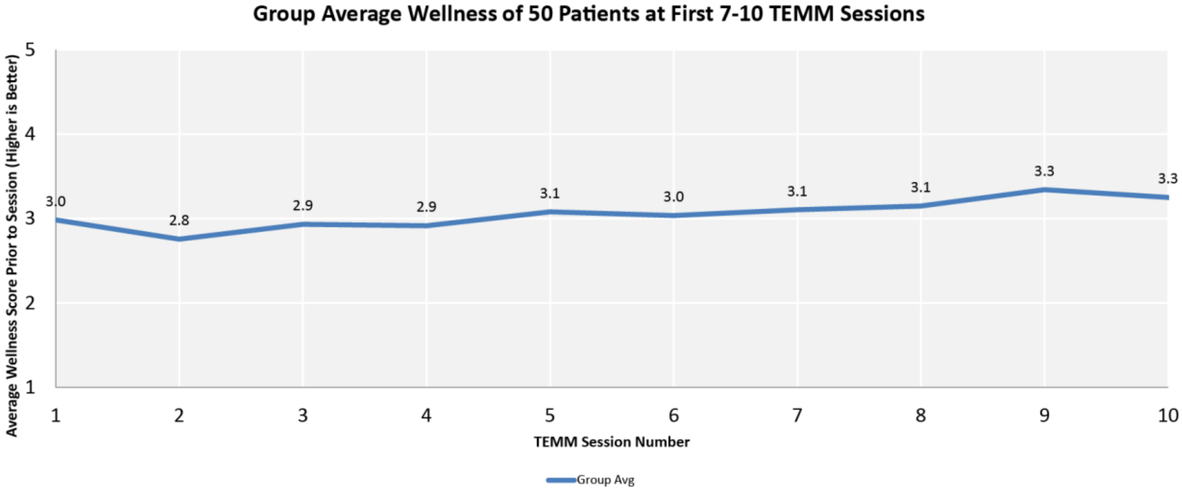

Figure 4. *50-patient trend of average patient wellbeing over time shows a modest net increase*.

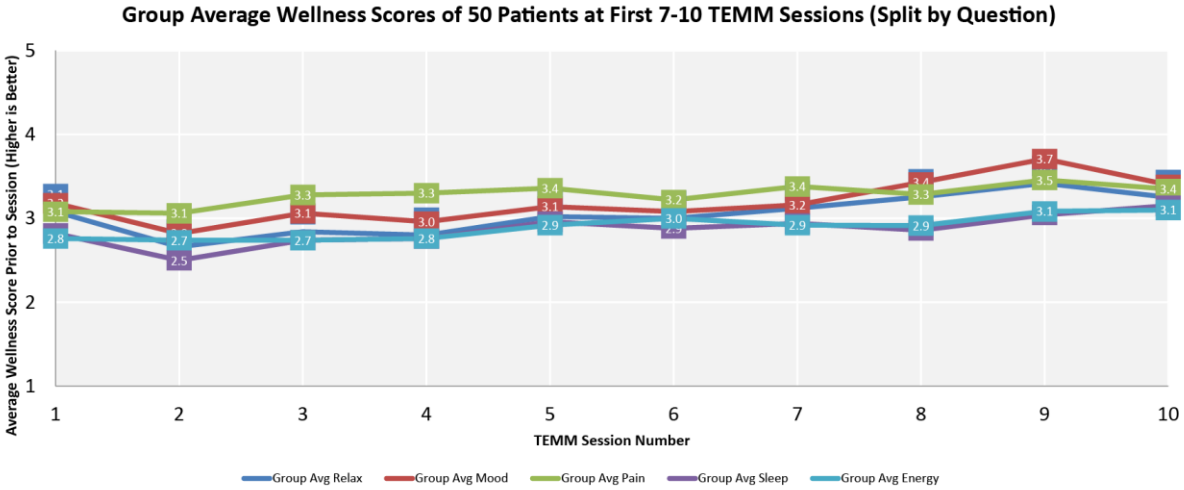

Figure 5. *50-patient wellbeing trend split by question.*

To this end, the actual nascent VR health/wellness therapeutics industry is now at a crossroads of ideally informing the technology market of what is useful and helpful for medical or mental health care, as opposed to the tech sector driving the conversation on a top-down level without the expertise or knowledge of what an individual with an illness or disability actually needs to recover or maintain their wellbeing. The often severe challenges that hospitals, clinics, clinicians and patients have encountered with the vast array of existing EMR's underscores this challenge and opportunity for the VRT community.

How to make an abundance of complex data less overwhelming is a key question in product evaluation for electronic health records. Usability is most certainly one part of the answer, as we have previously argued (Moller and Saynor, 2014, Moller et al 2015), and here it must be explicitly stated that the "user" is the patient and clinician, and not the "man-behind-the-curtain" digital designer. This means that, as with VR therapeutics, no matter how innovative or aesthetically appealing a VR program may be, without ongoing, often laborious iterative upgrades in arriving at a better and better fit between user needs/preferences and the evaluation tool, it quickly is threatened with obsolescence.

In general, our observation is that patients left with an open invitation to offer up qualitative supplementary data (e.g. unique psychosocial life situations that may significantly affect rote symptom report at the time of therapeutic engagement) will not frequently volunteer this unless specifically monitored or prompted, meaning that much more creativity is needed on behalf of design teams to elicit meaningful qualitative data to inform about user experience.

On a neuroeconomics level, the "low-risk" path of least resistance of putting in minimum effort required to obtain "reward" of completing the therapeutic endeavour likely remains the health-care consumer's most frequent choice on the utility curve (Becker et al, 1964). For this reason we have previously advocated for inclusive design usability approaches in VR therapeutics that, not just because making things easier to understand or enjoyable for a disabled individual is often the morally right thing to do on a public health level, but also because fun, "easy-to-use" and inherently engaging health-care consumer products are also those with the greatest market potential.

Evidently, most battle-weary clinicians in the mental health or physical medicine rehabilitation trenches would rather look at an easy-to-grasp Gestalt that captures the salient features of clinical progress, compared to "business as usual" standards in paper and/or electronic diagnostics. These currently consist of either manually combing through clinical notes or unorganized spreadsheet of data that is not organized into an experience readily digested by the clinician. In fact, it is puzzling that data visualization optimization has not been a focus of intense research and development by electronic health record vendors. (Bach et al, 2015)

3. CONCLUSIONS

In closing, when we introduced the imperative of usability and gold standards in EHR's related to VR/immersive diagnostics based on a generalized health-care culture of managed structural adjustment of patient experiences, we did not intend to imply that there can be no further room for creativity from designer/implementer or clinician.

On a public health level, once patients are assessed on high volume, rapid-fire level in a clinical setting that is more difficult to control than a research environment, the ability to efficiently track salient patient progress patterns is extremely valuable. Rather than viewing clinicians and researchers embracing VR as participating in an increasingly mechanistic or inhumane paradigm, we demonstrate that with the use of inclusive and iterative design processes the entire care flow from demographic data acquisition to symptom elucidation to momentary and longitudinal self-state reports can be optimized and even *authenticated*. With this last term, we refer to the existential Heideggerian notion of *being-in-the-world authenticity* (Steiner & Reisinger, 2006) that is also of interest in leisure/recreation experience industries like tourism and hospitality. Here, by accommodating to understandings of consumer tastes, preferences as well as ease of understanding and usability, relevant data can be more readily volunteered in a manner that seems less extractive and more akin to a playful flow-state, which we would argue is more akin to our natural state of consciousness.

While we do not necessarily suggest that our conceptual digital model of the busy clinician's critical opening line of "how are you doing?" is all-encompassing or negates others, we point to its popularity and acceptance rate in our clinic population amongst frequently quite disabled patients, and our experience in employing it clinically on a routine basis over the past year. Wellpad is driven by a pragmatic need to triage patient care plans (e.g. specialist referrals or medication changes based on specific symptom clusters); alongside this, by a desire to transition the "interview" into a humanized discussion to make the patient/consumer feel understood, while making the experience less burdensome and enjoyable for clinicians.

We continue to support and be engaged in system optimization, including incorporation of real-time data flow, whether physiological or camera-captured. Further research more fully exploring the concept of *Global Medical Wellbeing* Assessment is also warranted. As a clinical research and development team accustomed to the need for a fluid exchange between theory and praxis, we finally emphasize the importance of iterative design and continuous quality improvements to closer approximate tool optimization, whether therapeutic or diagnostic.

Acknowledgements: We are grateful to our participants for providing feedback on the Wellpad design and PRAXIS colleagues Kunal Sudan and Robelyn Soriano for collecting data and assisting patient intake.

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Applying Bayesian modelling for inclusive design under health and situational induced impairments

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ABSTRACT

Predictive pointing enables realising smart interfaces, which are capable of inferring the user intent, early in the pointing task, and accordingly assisting the on-display target acquisition (pointing and selection). It adopts a Bayesian framework to effectively model the user pointing behaviour and incorporate the present perturbations induced by situational impairments as well as inaccuracies in the utilised sensing technology. The objective of the predictive pointing system is to minimise the cognitive, visual and physical effort associated with acquiring an interface component when the user input is perturbed due to a situational impairment, for example, to aid drivers select icons on a display in a moving car via free hand pointing gestures. In this paper, we discuss the ability of the predictive pointing or display solution to simplify and expedite human computer interaction when the user input is perturbed due to health induced impairments and disability, rather than a situational impairment. Examples include users with tremors, spasms, or other motor impairments. Given the flexibilities acceded by the Bayesian formulation, the applicability of the predictive pointing to inclusive design in general is addressed. Its intent prediction functionality can be adapted to the user's physical capabilities and pointing characteristics or style, thereby catering for wide ranges of health induced impairments, such as those arising from ageing. It is concluded that predictive displays can significantly facilitate and reduce the effort required to accomplish selection tasks on an interactive display when the user input is perturbed due to health or physical impairments, especially when pointing in 3D with free hand pointing gestures.

1. INTRODUCTION

Interactive displays, such as touchscreens, are becoming an integrated part of the car environment due to the additional design flexibilities they offer (e.g. combined display-interaction-platform-feedback module whose interface can be adapted to the context of use through a reconfigurable Graphical User Interface GUI) and their ability to present large quantities of information associated with In-Vehicle Infotainment Systems IVIS (Burnett et al, 2001 and 2011, Harvey and Stanton, 2013, Jaegr et al, 2008). The latter factor is particularly important since the complexity of IVIS has been steadily increasing to accommodate the growing additional services related to the proliferation of smart technologies in modern vehicles (Bishop, 2005). Using an in-car display typically entails undertaking a free hand pointing gesture to select an on-screen GUI icon. Whilst this input modality is intuitive, especially for novice users, it requires dedicating a considerable amount of attention (visual, cognitive and physical) that can be otherwise available for driving (Jaegr et al, 2008). Additionally, the user pointing gesture and input on the display can be subject to in-vehicle accelerations and vibrations due to the road and driving conditions, which can lead to erroneous selections (Ahmad et al 2015). This source of perturbations is dubbed Situationally Induced Impairment and Disability (SIID). Figure 1 depicts an example of 3D pointing gestures subjected to high levels of perturbations (i.e. SIID) in a moving car. The notable impact of the in-vehicle SIID originated perturbations is clearly visible in the pointing motion as jolts or jumps. Adapting to the present noise and/or rectifying incorrect selections will tie up more of the user's attention. This can render interacting with the touchscreen highly distracting, with potential safety consequences (Jaegr et al, 2008, Ahmad et al, 2015).

Predictive interactive displays, proposed in (Ahmad et al, 2016), utilise a gesture tracker to capture, in real-time, the pointing hand/finger locations in 3D in conjunction with appropriate probabilistic destination inference algorithm. It can establish the icon the user intends to select on the display, remarkably early in the free hand pointing gesture, and in the presence of perturbations due to road and driving conditions, i.e. SIID. The smart intent-aware display then accordingly simplifies and expedites the target acquisition by applying a *pointing facilitation scheme*. The latter involves expanding the intended GUI icon or even selecting the predicted item on behalf of the user, who need not touch the display surface. It is noted that several pointing gesture trackers, which can accurately track, in real-time, a pointing gesture in 3D, have emerged lately, e.g. Microsoft Kinect, leap motion and others. They are motivated by extending Human-Computer Interaction (HCI) beyond traditional keyboard input and mouse pointing. Therefore, predictive displays can notably improve the usability of in-car interactive displays by reducing distractions and workload associated with using them. The Bayesian formulation of the fundamental problem of intent inference, see (Ahmad et al, 2016), enables the predictive displays to effectively handle varying levels and types of present SIID-originated perturbations and/or user pointing behaviour as well as incorporating additional sensory or contextual data when available.

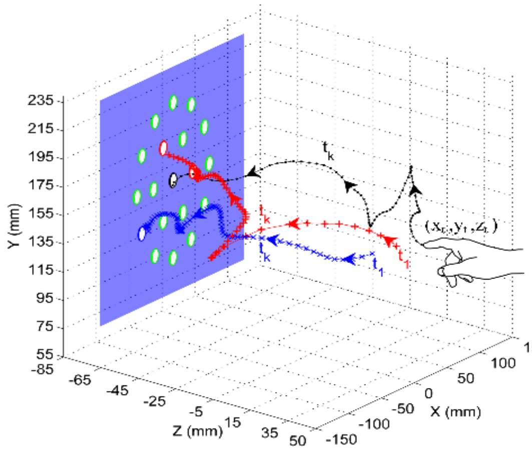


Figure 1. *Full pointing finger-tip trajectories in 3D during three pointing gestures aimed at selecting a GUI item (circles) on the in-vehicle touchscreen surface (blue plane), whilst the car is driven over a harsh terrain with severe perturbations present. Arrows indicate the direction of travel over time, starting at* $t_1 < t_k$.

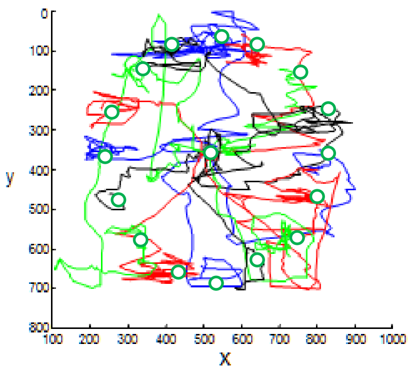


Figure 2. *Several 2D mouse cursor tracks to acquire on-screen GUI icons (classical Fitt's law task, ISO 9241) for user with cerebral palsy (Langdon et al, 2006).*

On the other hand, using technological devices and the ubiquitous touchscreens becoming commonplace in everyday life, whether in work or domestic environments, led to the task of acquiring targets on a graphical user interface (e.g. to select buttons, menus, etc.) being a part of modern life and a frequent human-computer interaction undertaking. Hence, facilitating on-screen target acquisition (pointing and selection), reducing the effort incurred and improving its accuracy is critical for realising effective user interfaces. This is typically tackled by applying a pointing assistive strategies (e.g. expanding icon, altering its activation area, etc.), preceded by a mechanism to establish the intended GUI icon, i.e. to identify which icon to expand or alter, for example see (MacKenzie, 1992, Kopper et al, 2010, Meyer et al, 1988, McGuffin and Balakrishnan, 2005, Murata, 1998, Wobbrock et al, 2009, Asano et al, 2005, Ziebart et al, 2012, Pasqual and Wobbrock 2014, Ahmad et al 2014). Whilst the user population is diverse and includes motion impaired, elderly and non-expert users, these HCI studies often consider able-bodied computer users and focus on pointing in 2D on a computer screen using a mouse or a mechanical device. However, similar to users experiencing SIID, the pointing-selection task can be challenging for users with a motion-visual impairment, i.e., Health Induced Impairment and Disability HIID (Ahmad et al, 2014, Langdon et al 2006, Keates et al, 2002, Gajos et al, 2007, Biswas and Langdon, 2012, Domingo, 2012), for example, Figure 2 shows 2D mouse cursor pointing tracks of a user suffering from cerebral palsy. The prediction approaches developed for mouse pointing are also in general unsuitable for pointing in 3D using free hand pointing gestures and/or have high computational-training requirements (Ahmad et al, 2016). Thereby, suitable prediction algorithms for pointing in 3D under situational impairment are proposed in (Ahmad et al, 2016), within a flexible Bayesian framework. In (Ahmad et al, 2014 and 2016) statistical techniques based on Kalman filtering and advanced state-space particle filter method are employed to smooth 2D pointing mouse cursor trajectories and 3D tracks of free hand pointing gestures. They compensate for (remove) HIID and SIID related perturbations, such that the resultant 2D or 3D pointing trajectories move only in the intended direction.

In this paper, we highlight the potential of applying the predictive display solution, which was developed for perturbations due to SIID in automotive contexts and supports pointing gestures input modality in 3D, to facilitate HCI for users with a wide range of health induced impairment and disability. This includes HIID that arises from age, and not only severe forms of physical disability. Therefore, this HCI solution can be viewed as a means to promote inclusion. Inclusive design examines designed product features with particular attention to the functional demands they make on the perceptual, thinking and physical capabilities of diverse users. A predictive display can extend the usability of the interactive displays to a diverse population of users, for example, motion impaired or able-bodied users, elderly or young users, expert or non-expert users as well as those that are situationally impaired.

Here, we exploit the transferability of HCI solutions for HIID to SIID scenarios (and vice versa) as proposed in (Sears et al, 2003, Biswas and Langdon, 2012). This transferability assumes that any human user can be impaired (disabled) in their effectiveness by characteristics of their environment, the task and the design of the GUI. Such impairment may take the form of perceptual, cognitive and physical movement functional limitations, which translate into inability. For instance, attempting to enter text on an in-car touchscreen (e.g. for navigation) whilst driving in an off-road environment presents difficulties in perceiving the interface for multiple tasks (seeing on-screen icons, outside driving environment and vehicle controls), performing the attentional tasks necessary for safe driving (track/correct vehicle movement, maintaining car controls as well as monitor/correct the texting task), and carrying out the required physical movements (pointing, pressing, steering, braking, etc.). The Bayesian intent predictor applied within a predictive display system relies on defining a Hidden Markov Model (HMM) of the pointing motion in 3D, effectively capturing the influence of the intended endpoint on the pointing finger/hand movements (Ahmad et al, 2016). This is distinct from previous HCI research on endpoint prediction in 2D scenarios, e.g. (Kopper et al, 2010, Meyer et al, 1988, McGuffin and Balakrishnan, 2005, Murata, 1998, Wobbrock et al, 2009, Asano et al, 2005, Ziebart et al, 2012, Pasqual and Wobbrock 2014), which often follow from Fitt's law type analysis and uses a static setting/model. The statistical modelling approach permits capturing the variability among users, motor capabilities and the noise of the motion tracking sensor via Stochastic Differential Equations (SDE) that represent the destination-motivated pointing motion in 3D or even 2D.

2. INCLUSIVE DESIGN FROM DISABILITY TO HCI

Increasingly, mobile technology is proliferating, and due to the expected contribution of the Internet of Things (IoT), 5G and recent mobile communications technology, a plethora of possible applications integrating sensor networks, cloud based processing and storage and mobile contexts will present HCI challenges to interaction designers (Atzori et al, 2010, Domingo, 2012). Challenges range from: network latencies, and lack of them; processing limitations; fusion of multiple sources of data, and the potential to overload the user's capabilities, both in terms of physical responses and also cognitive capacity. The field of inclusive design relates the capabilities of the population to the design of products by better characterising the user–product relationship. Inclusion refers to the quantitative relationship between the demand made by design features and the capability ranges of users who may be excluded from use of the product because of those features. By 2020, almost half the adult population in the UK will be over 50, with the over 80s being the most rapidly growing sector. These "inclusive" populations contain a great variation in sensory, cognitive and physical user capabilities, particularly when non-age-related impairments are taken into account. Establishing the requirement of end users is intrinsically linked to the user centred design process. In particular, a requirements specification is an important part of defining and planning the variables to be tested and measured as well as the technology use cases to be addressed during the user trials.

In particular, inclusive design is a user-centred approach that examines designed product features with particular attention to the functional demands they make on the perceptual, thinking, and physical capabilities of diverse users, particularly those with reduced capabilities and ageing. It is known, for example, that cognitive capabilities such as verbal and visuospatial IQ show gradually decreasing performance with aging. Attending to goal-relevant, task features and inhibiting irrelevant ones is important in interaction and this is known to be affected by ageing. Attentional resources may also be reduced by ageing, such that more mistakes are made during divided attention, dual task situations (Schaie et al, 2003, Newell, 2006, Petrie, 2001). Another perspective on inclusive design is that of ordinary and extraordinary design that aims to improve design for older, impaired users of low functionality while at the same time enhancing design for the mainstream and ordinary users in extreme environments. On this basis, design should focus on the *extraordinary* or impaired first, accommodating mainstream design in the process (Newell et al, 2011).

Not all functional disabilities result from ageing. Some common examples of non-age-related impairment include specific conditions such as stroke and head injury, which may affect any or all of perception, memory and movement. Other conditions are generally associated with movement impairment. For example, Parkinson's disease and cerebral palsy involve damage to the brain causing effects such as tremor, spasms, dynamic coordination difficulties, and language and speech production impairment. Of course, many other conditions such as Down's syndrome and multiple sclerosis may affect cognitive capability either directly, through language learning and use, or indirectly through its effects on hearing, speech production and writing. Of all the variations discussed, many differentially affect normal population ranges of capability. They may be rapidly changing and vary in intensity both within and between individuals, leading to a demanding design environment that requires close attention to conflicting user requirements and a better understanding of user capability. Again, this confirms that interaction design for future generations of products must be inclusive.

One area offering mitigation to these challenges is design of integrated multimodal display and control technologies for ease of input and task completion (Langdon et al, 2006, Keates et al, 2002, Gajos et al, 2007, Biswas and Langdon, 2012). Initially, in the domain of better design for elderly and impaired computer and TV users, this work is directly transferrable to the domain of the situationally impaired interface disability users as proposed by (Sears et al, 2003) and in the form of extraordinary user interfaces (Newell et al, 1997). This approach assumes that any human user can be impaired (disabled) in their effectiveness by characteristics of their environment, the task, and the design of the user interface they are presented with. Importantly, an inclusive design approach extends beyond the scope of conventional usability methods as it must accommodate extremes of capability range or situational contexts of task or stress, that are not normally accommodated by product design. For this reason, the predictive interactive display within a Bayesian framework is well suited to the human centred design of new information-rich and multimodal interfaces. It can effectively incorporate variabilities in physical-motor capabilities, interaction style, contextual information and additional sensory data (when available), within the stochastic pointing movement and measurement models as well as the modelling priors. In this paper, we start with a specific case, whereby the proposed statistical predictive techniques aim to facilitate the GUI icons acquisition on an in-vehicle touchscreen by a driver in a moving car, i.e. the pointing gestures can be heavily perturbed due to SIID. This has proven to be very effective in reducing the workload associated with using an interactive in-car display. Thus, the developed predictive displays framework is a promising approach to achieving substantial significant usability improvements to health impaired users, i.e. HIID, in similar pointing tasks. If so, this solution can significantly enhance the HCI capabilities of individuals with severe physical impairments such as tremor, spasm and athetosis.

3. BAYESIAN FORMULATION AND SUITABILITY

The free hand pointing gesture movements towards an on-screen item in 3D are not deterministic, but are rather governed by a complex motor system subject to numerous physical constraints. The gesture can also be subjected to external motion, jolting, rolling, acceleration (e.g. in a moving platform). Nonetheless, stochastic models can capture the inherent uncertainty in the pointing finger movements, albeit being driven by intent. This implies that predictions of the pointing object motion are not single deterministic paths, but are rather probabilistic processes, with the pointing finger position at a future time expressed as a probability distribution in space. By adequately incorporating this uncertainty, relatively simple models of the pointing finger motion can be used successfully to track finger movements and evaluate the corresponding *observation likelihoods*. It is emphasised that the objective of a predictive pointing is not to accurately model the complex human motor (pointing) system. Formulating approximate pointing motion models that enable determining the on-display endpoint (i.e. intent) of a free hand pointing gesture suffices. Therefore, calculating the transition density of a stochastic model, for example, between two successive observation times is required to condition the tracked pointing finger state $\mathbf{X}_t$, (e.g. position, velocity, etc.) on a nominal endpoint on the display $\mathcal{D}_i$. Continuous-time motion models are a natural choice in such cases, where the tracked pointing object's dynamics are represented by a continuous-time stochastic differential equation (SDE). This SDE can be integrated to obtain a transition density over any time interval. Although numerous models for object tracking exist, the class of Gaussian linear time invariant (LTI) models for the evolution of $\mathbf{X}_t$ has proven to be effective to establishing the user intent and also lead to a low-complexity inference procedure. This class includes many models used in tracking applications, such as constant velocity and the linear destination reverting (LDR) models.

3.1 Intent Inference

Predictive displays aim to estimate, in real-time, the probability of each of the selectable icons of the displayed GUI being the intended endpoint of the undertaken pointing task. At time instant t_k where the available pointing object (finger or mouse cursor) observations (e.g. positions) are $\mathbf{m}_{1:k} = \{\mathbf{m}_1, \mathbf{m}_2, \dots, \mathbf{m}_k\}$, the system calculates

$$\mathcal{P}(t_k) = \{P(\mathcal{D}_i = \mathcal{D}_I | \mathbf{m}_{1:k}),\ i = 1,2,\dots,N\}. \quad (1)$$

The intended destination, which is unknown *a priori*, is notated by $\mathcal{D}_I$ such that $\mathcal{D}_I \in \mathbb{D} = \{\mathcal{D}_1, \mathcal{D}_2, \dots, \mathcal{D}_N\}$ and $\mathbb{D}$ is the set of selectable GUI items. It is noted that the locations of the interface components in $\mathbb{D}$ are known, however, no assumptions are made on their distribution or layout on the display. Following Bayes' rule, we can write: $P(\mathcal{D}_i = \mathcal{D}_I | \mathbf{m}_{1:k}) \propto P(\mathcal{D}_i = \mathcal{D}_I) P(\mathbf{m}_{1:k} | \mathcal{D}_i = \mathcal{D}_I)$, for each of the selectable GUI icons. This prior is independent of the current pointing task and can represent contextual information, user profile, frequency of use, etc. Sequentially determining the probabilities in (1) demands only calculating the likelihoods $P(\mathbf{m}_{1:k} | \mathcal{D}_i = \mathcal{D}_I)$ at the arrival of a new observation (i.e., up-to-date position of the pointing finger or mouse cursor).

After evaluating $\mathcal{P}(t_k)$ in (1), a simple intuitive approach to establish the intended destination at t_k is to select the most probable endpoint via

$$\hat{I}(t_k) = \underset{\mathcal{D}_i \in \mathbb{D}}{\arg\max}\, P(\mathcal{D}_i = \mathcal{D}_I | \mathbf{m}_{1:k}). \quad (2)$$

Decision criterion other than (2) can be applied with the Bayesian framework, see (Ahmad et al, 2016). For the linear destination reverting models, Kalman filters can be used (one per nominal destination) to calculate $P(\mathcal{D}_i = \mathcal{D}_I | \mathbf{m}_{1:k})$ in (1) as per (Ahmad et al 2016). Adopting nonlinear motion or observation models can lead to advanced statistical inference methods such as sequential Monte Carlo or other related methods for online filtering.

3.2 Linear Destination-Reverting Motion Models

Since the pointing motion is intrinsically driven by the intended on-screen icon, destination-reverting models can be suitable for predictive pointing under health or situationally induced impairments. Following the integration of their respective SDEs and assuming that the intended endpoint is $\mathcal{D}_i$, LDR models can be expressed by

$$\mathbf{X}_{i,k} = \mathbf{F}_{i,k} \mathbf{X}_{i,k-1} + \boldsymbol{\kappa}_{i,k} + \mathbf{w}_k, \quad i = 1,2,\dots,N \quad (3)$$

where $\mathbf{X}_{i,k-1}$ and $\mathbf{X}_{i,k}$ are the hidden model state vectors at two consecutive time instants t_{k-1} and t_k. For example, the state $\mathbf{X}_{i,k}$ can include the true pointing-finger location in 2D or 3D and other higher order motion dynamics such as velocity, acceleration, etc. Matrix $\mathbf{F}_{i,k}$ is the state transition and $\boldsymbol{\kappa}_{i,k}$ is a time varying constant (both are with respect to $\mathcal{D}_i$), and the motion model dynamic noise is $\mathbf{w}_k$. For $\mathcal{D}_i \in \mathbb{D}$ possible endpoints on the display (i.e. selectable GUI icons), N such models can be constructed and their corresponding likelihoods are calculated with the appropriate statistical filtering algorithm where the (also) linear observation model is given by

$$\mathbf{m}_k = \mathbf{H}_k \mathbf{X}_{i,k} + \mathbf{n}_k. \quad (4)$$

The noise introduced by the sensor is represented by $\mathbf{n}_k$. For more details on the LDR models and their characteristics with and without the bridging distributions, the reader is referred to (Ahmad et al, 2015 and 2016).

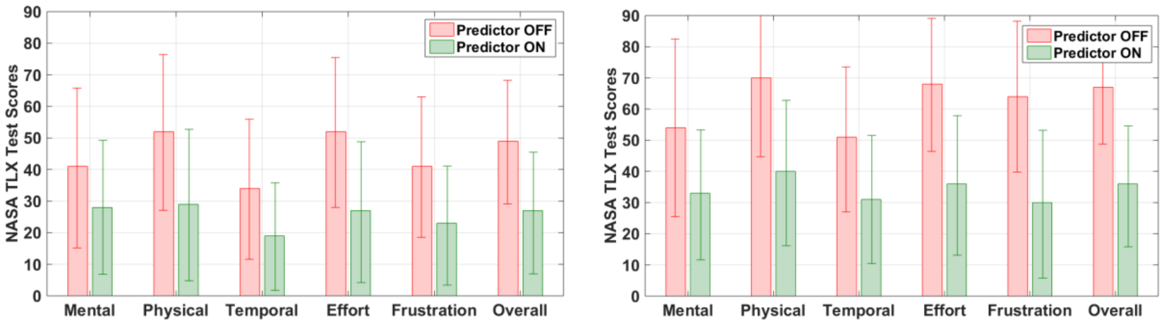
Bayesian inference with a hidden Markov model offers flexibility in terms of modelling the pointing motion with either HIID or SIID via the SDE and its integration in (3) and (4). We recall that the variability in the pointing movement, e.g. due to the user behaviour and/or impairment, can be introduced through the noise element of the state $\mathbf{X}_k$ and the noise generated from the employed sensor (e.g. a particular gesture tracker) can be incorporated via the measurement noise in the observation equation. Most importantly, the statistical filter utilised to determine the intent of the tracked object (e.g. mouse cursor in 2D or pointing finger for free hand pointing gestures in 3D) can be applied to the same class of motion models, albeit altering the applied pointing motion model.

3.3 Smoothing Noisy Trajectories

The results of the N statistical filters applied to determine $\mathcal{P}(t_k)$ in (1) can be utilised to remove the unintentional perturbations-impairment-related movements as shown in (Ahmad et al, 2016). However, in certain scenarios (e.g. severe perturbations) where it is desirable to maintain a simple linear motion model for the intent inference functionality, a pre-processing step/stage can be added such that the raw pointing data is filtered, e.g. using a particle filter (Langdon et al, 2006, Ahmad et al, 2014). The filtered track is subsequently used by the destination inference module. The effectiveness of the state-space-modelling for removing unintentional impairment-related pointing movement were demonstrated in (Langdon et al, 2006, Ahmad et al, 2014, 2015 and 2016).

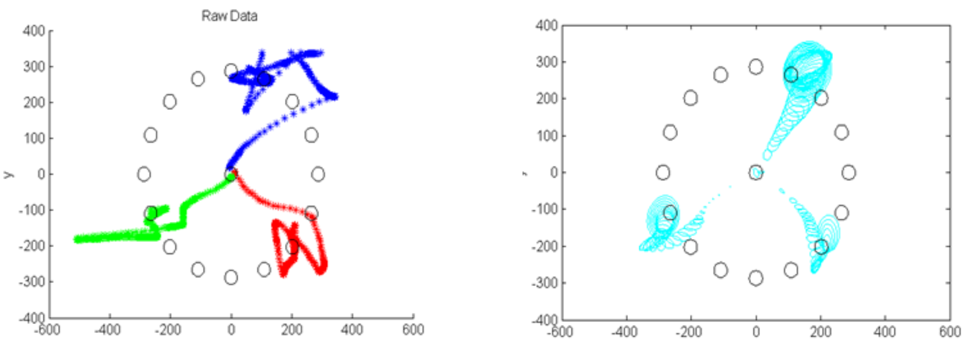
3. EXAMPLES: SITUATIONAL AND MOTOR IMPAIRMENTS

Figure 3 depicts results of utilising an in-vehicle predictive display under varying levels of SIID due to road/driving conditions when the predictive capability is off and on. In the former case, the experiment becomes a conventional task of interacting with an in-car touchscreen where the user has to physically touch the intended icon on the screen to select it. The benefits of the predictive display are assessed in terms of the system ability to reduce the workload of interacting with the in-car touchscreen and the pointing tasks durations T_p. NASA TLX forms, widely utilised in HCI studies, are used to evaluate the subject workload experienced by the users. In this study, a Leap Motion controller is employed to produce, in real-time, the locations of the pointing finger in 3D, i.e. $\mathbf{m}_k = [x_{t_k}\ y_{t_k}\ z_{t_k}]'$



(a) *(b)*

Figure 3. *Workload scores for interacting with an in-vehicle touchscreen with and without the predictive capability for 20 participants under varying levels of experienced in-vehicle perturbations (Ahmad et al 2016). (a) Minimum perturbations (motorway); (b) Mild-severe perturbations (badly maintained road).*



(a) *(b)*

Figure 4: *Filtering noisy mouse cursor trajectories due to HIID using a particle filter and showing the confidence ellipses (Langdon et al, 2006). (a) Raw noisy 2D cursor trace data; (b) filtered traces. Units on the axes are pixels.*

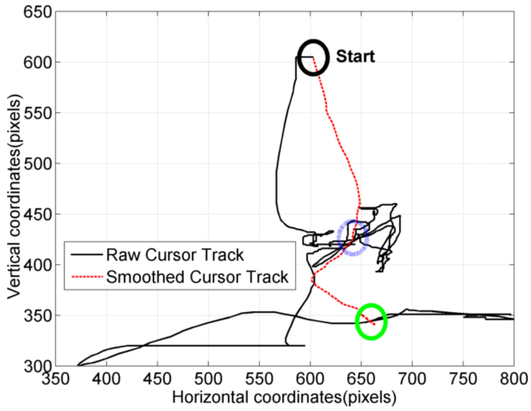


Figure 5. *Smooth cursor track in 2D for a severe HIID-related perturbations (Ahmad et al, 2014). User is targeting two GUI icons (target 1 is the blue circle and then target 2 is the green circle). The start point is the black circle.*

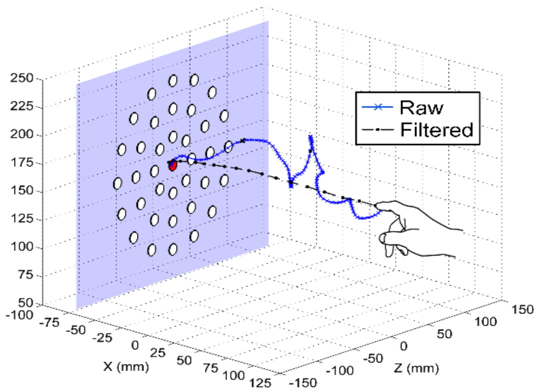


Figure 6. *3D pointing track before (blue) and after (dashed) applying a variable rate particle filter (Ahmad et al, 2014).*

at t_k. Pointing finger observations are then employed by the probabilistic intent predictor to calculate the probabilities $\mathcal{P}(t_k)$ in (1). The predictive display auto-selects the intended on-screen icon once a particular level of prediction certainty is achieved (the user need not touch the display surface to make a selection). This pointing facilitation scheme is dubbed *mid-air selection* (Ahmad et al, 2016). Figure 3 demonstrates that the predictive display system can reduce the workload of interacting with an in-car display by nearly 50%. It can also be noticed that workload notably increases as more perturbations are experienced. Measured durations of pointing task also show that T_p can be reduced by over 35% under mild to severe accelerations-vibrations due to the road conditions (e.g. driving on a badly maintained road). Therefore, the predictive display system that uses a suitable Bayesian formulation can significantly simplify and expedite on-screen target acquisitions via free hand pointing gestures.

Figures 4 and 6 illustrate the ability of a sequential Monte Carlo method, namely the variable rate particle filter, to remove highly non-linear perturbation-related unintentional pointing movements when interacting with a touchscreen using pointing gestures in 3D and selecting icons of a GUI displayed on a computer screen via a mechanical mouse. Whereas, in Figure 6 Kalman filtering is applied. The raw cursor movement data in Figures 4 and 5 is for a user that suffers from cerebral palsy. Figure 4 exhibits the confidence ellipses obtained from the sequential Monte Carlo filter, which has visibly removed the health-induced-impairment jumping behaviour of the mouse cursor position and can assist identifying the user's intended destination (despite the ambiguity of the raw pointing data). On the other hand, unintentional situational-induced-impairment-related pointing finger movements in 3D are successfully removed in Figure 6.

4. CONCLUSIONS

Using the Bayesian formulation developed for able-bodied touchscreen users in a perturbed environment has proved successful in improving performance and reducing workload. There is no reason to suppose these benefits may not be realised in the case of health-induced impairment and disability. We reported preliminary tests of this assumption, providing promising results. Spasm, weakness, tremor and athetosis can be mitigated or largely eliminated by the predictive approach based on the described Bayesian algorithms, original developed for automotive applications. In particular, motion impaired users, who may have difficulty pointing-selecting on interactive displays will benefit not only from prediction and automated selection (i.e. auto-selection), but also from the reduction of workload reported by the automotive trial participants, measured using NASA TLX scores.

Additionally, from an inclusive design perspective, the predictive display technology may greatly benefit those with age related or mild physical or perceptual impairments by enhancing performance in pointing-selection and reducing the associated workload. Mild functional impairments such as physical movement (reach and stretch, dexterity), visual acuity, and cognitive capacity could be improved. This predictive approach is also applicable to special purpose designs for specific cases, extreme impairment and disability. Experimental studies will be superseded by trials of the same algorithms and detection technologies with interfaces in mobile displays, walking scenarios, wheelchair use and on public transportation. Predictive displays are capable of incorporating and fusing additional sensory data or input modalities, e.g. eye-gaze or voice-based commands, via the Bayesian framework succinctly described in this paper. In conclusion, encouraging results suggest that these specific advanced predictive algorithms for pointing and selection have utility in a range of interfaces where performance is impaired, whether by situation or by health. The heath based impairment is a rich area for future investigation.

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Tele-guidance based orientation and mobility system for visually impaired and blind persons

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ABSTRACT

The design and development of tele-assistance services have received great consideration in the domain of healthcare lately. Telecare solutions are seen as a potential means of addressing the future care needs of ageing societies. With the growing proportion of dependent people (ageing, disabled users), tele-assistance and tele-monitoring platforms will play a significant role to provide efficient and less-costly remote care and support. It will allow aged and disabled persons to maintain their independence and lessen the burden and cost of caregiving. In the case of visually impaired persons (VIP) and blind persons, guide dogs and white canes provide them a fair degree of independence. However, those are very limited in guiding the user towards a specific desired location, especially in an unknown environment. The assistance of other people presents a feasible solution, though it does not improve the idea of autonomous guidance and privacy. The concept of proposed tele-guidance system is based on the idea that a blind pedestrian can be assisted by spoken instructions from a remote caregiver who receives a live video stream from a camera carried by her. The assistive tools have reportedly acceptance issues by VIP. The paper also presents a qualitative study using a modified version of UTAUT-2 (Unified Theory of Acceptance and Use of Technology) to find out causes for acceptance issues in navigation tools for visually impaired. Another goal of the study was to validate the UTAUT2-model as suitable for researching acceptance issues of navigation assistance tools of VIP.

1. INTRODUCTION

Vision loss is a serious impairment that deprives a human of approx. 80–90% perceptual abilities and has a detrimental effect on professional, social and personal quality of life. It is estimated that there are 285 million VIP in the world, 39 million of these being completely blind. 82% of the blind people are aged 50 years or more. The growing number of elderly people results in increased problems caused by the old age such are chronic eye diseases (WHO Global Data on Visual Impairments, 2010). Even in modern societies, common understanding of blindness and the needs of the VIP are poorly identified. The white cane and more rarely a guide dog are the primary mobility aids that are mainly associated with this disability. In spite of recent remarkable advancements in information and communication technologies (ICT) and electronics miniaturization, the devices that are termed as Electronic Travel Aids (ETA) are very slowly fighting their ways into the community of VIP. In fact, no single ETA has been widely accepted by the VIP and blind as a useful aid (Bourbakis, 2008).

ETA is the general term encompassing a large class of assistive devices aiding the VIP in mobility. There has been a long lasting research record on ETAs helping the blind in obstacle avoidance and navigation. The idea of sensory substitution, i.e. replacing lack of stimuli from one sense by appropriate stimuli for another sense is the operating principle of all ETAs for the blind (Bourbakis, 2008).

The following is a functional, rather than technological classification of these assistive devices (Strumillo, 2012):

1. Obstacle Detectors
2. Environment Imagers
3. Orientation & Navigation Systems (ONSs)

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The first two classes of aids are personal (wearable) devices that scan the environment in personal and near spaces. These devices have the task to assist blind people to intercept obstacles on their path. On the other hand, the third group of aids are the systems that offer sensing of far spaces and can acquire data from larger scale distributed networks, e.g. GPS, GIS, Digital Maps, and through wide access to the Internet and Wireless Communication Networks (e.g. RFIDs, Bluetooth, Wi-Fi, and GSM). An innovative class of ONSs is based on guiding the VIP by a remote human guide termed as tele-assistance/tele-guidance systems (Strumillo, 2012). The underpinning idea of this class of ETAs is that a blind pedestrian is guided by spoken instructions from a remote caregiver who remotely receives a video stream from a camera carried by the blind user. The remote vision facility permits the remote sighted guide to navigate the visually impaired user of the system in the immediate travel environment i.e. micro-navigation; e.g. the assistance in the avoidance of obstacles and other hazards in the path of travel, while the GPS and GIS data facilitates the navigation through the environment on a large scale i.e. macro-navigation.

The first reported system for remote guidance of the blind, was the system developed at the Brunel University, UK (Garaj el al., 2003). Three ICT technologies were combined to offer the tele-assistance functionality; namely, GPS (Global Positioning System), GIS (Geographic Information System) and video/voice transmission over the 3G mobile network. The system comprises of two units. The backpack mobile unit equipped with a portable camera and an audio headset that was carried by the blind user and a stationary PC based unit for remote caregiver. (Bujacz et al., 2008A) developed a tele-assistance system using GPS, Digital maps, Bluetooth, and voice/video link was established over the GSM network within the High-Speed Downlink Packet Access (HSDPA). The system comprised of an ultra-mobile laptop computer worn in a shoulder bag, a digital webcam, and a GPS receiver attached to the shoulder strap, and a single-ear head-phone with a microphone and the assistant who remotely aided the VIP used any PC with a public IP address. In (Baranski, Polanczyk and Strumillo, 2010), the authors developed a remote guidance system where the visually impaired was equipped with a digital camera, a GPS receiver and a headset. Internet and GSM connections transmitted video/audio information and GPS data between the remote operator and the user. Using audio communication, the operator navigated the VIP towards a desired location and warned him about possible obstacles. Similar tele-assistance systems were developed by (Hunaiti, Garaj and Balachandran, 2006), (Bujacz et al., 2008B), (Koley and Mishra, 2012), for visually impaired pedestrians. In Japan, API AI Co (API AI Co, 2016) and BlindMaps (BlindMaps.org, 2016) are developing technology and prototypes for making the white cane a connected device which can act as an interface to the urban environment and to the user's smartphone, has very many ideas that have potential to complement such system.

The former tele-guidance systems either used bulky back packs or special purpose mobile terminals to be carried by the VIP. This fact effected the acceptability of such systems by VIP at large. The advancement in computation capabilities of mobile devices and electronics miniaturization presented newer possibilities for developers to develop more user-friendly tele-guidance systems for the VIP. The proposed tele-assistance based orientation and mobility system enables VIP to initiate a rich tele-guidance session with a remote caregiver when they need remote assistance during navigation. The remote caregiver can assist VIP remotely using voice commands and/or haptics/vibration based interfaces by using field of view of VIP and complementing data on his terminal.

2. SYSTEM DESCRIPTION

The proposed tele-guidance system comprises of two terminals, VIP's terminal and remote caregiver's terminal, Figure 1.

2.1 VIP's Terminal

The VIP's terminal has 4 components:

- *Smart phone.* It provides connectivity with the remote caregiver's terminal through Wi-Fi or GSM based internet connection. The video, voice, and location coordinates of VIP using smart phone GPS are transmitted over the internet to remote caregiver.
- *Bluetooth webcam.* A Bluetooth webcam that is connected to smart phone is mounted on the chest of the VIP. It will be used to send real time video of the field of view of the VIP to remote caregiver.
- *Bluetooth headset (Bluetooth earpiece, speaker).* The Bluetooth head set (mic and speaker) is used for voice communication between VIP and caregiver.
- *Smart Cane (Braille Cell, Directional Vibrators, Bluetooth Interface).* The smart cane contains directional vibrators for navigation assistance, tactile braille cell, and Bluetooth interface to connect/control it with the smart phone.

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It will enable VIP to initiate a need based rich tele-guidance (audiovisual) assistance session with a remote caregiver. The remote caregiver will receive the audio call and location coordinates of the VIP when the remote assistance session is initiated. If signals' quality is good, the caregiver will initialize the video channel to start video feed transmitted from from VIP. The remote caregiver will now start providing on site assistance to VIP remotely through voice commands or haptics/vibration interfaces of smart cane accordingly. During the remote tele-guidance session, VIP will be able to mute the voice channel anytime while video still on if she wants to make sense of the environment by listening surrounding sounds. The remote caregiver will get a notification about it.

The smart cane is being developed as part of this project to provide caregiver with extra modalities to assist VIP remotely. Especially as studies suggest, engaging VIP hearing during navigation is not recommended. The smart cane will be connected to the smart phone and will allow remote caregiver to assist VIP through vibration and haptics interfaces. This component will potentially extend the functionality of conventional voice-based tele-guidance ONS systems as presented before.

The VIP will be able to configure more than one person as his caregiver e.g. mother, father, relative or some professional or volunteer caregiver. If either of those higher in preferences is not available, the tele-guidance assistance request will be automatically transferred to the one available. All configured caregiver will receive an SMS alert on their phone if neither of them is available at any time when VIP calls for assistance.

Figure 1. *Tele-guidance system concept.*

2.2 Remote Caregiver's Terminal

The remote caregiver can either use a desktop workstation OR a tablet or phablet (big screen smart phone) as his terminal. It will transmit two-ways voice, render map data of the VIP's location coordinates, and display the real-time video of VIP's field of view. The live video stream will be used to assist VIP in micro navigation i.e. travelling in immediate path and avoiding obstacles. VIP's real time map data will enable the remote caregiver provide assistance in macro navigation i.e. in far field navigation to travel from one place to other remote place. The tele-guidance will be provided through spoken instructions or haptics and vibration based interfaces accordingly

The availability status (being online) of all configured caregivers of a VIP will be available to all available caregivers. This will facilitate them to mediate load of the guidance. As VIP will be able to mute caregiver's voice anytime during tele-guidance, it will be studied if there is a need for the remote caregiver to override muting if necessary e.g. in a possible hazardous situation ahead.

2.3 Technologies

The technologies selected to implement different features of the proposed tele-guidance system are:

- *Communication.* Wi-Fi or GSM based internet connection will be used for establishing voice, video call and transmitting GPS coordinates of VIP to remote caregiver.
- *Privacy.* To support privacy between VIP and remote caregiver, encrypted voice, video, and location data communication over the internet is chosen. Linphone API (Linphone, 2016) will be used to implement this functionality. Linphone is a free voice over IP (VoIP) service and SIP client. It supports ZRTP (Answers to your ZRTP Questions, 2016) for end-to-end encrypted voice and video communication.

- *ZRTP (composed of Z and Real-time Transport Protocol).* ZRTP is a cryptographic key-agreement protocol to negotiate the keys for encryption between two end points in a Voice over Internet Protocol (VoIP) phone telephony call based on the Real-time Transport Protocol. It uses Diffie–Hellman key exchange and the Secure Real-time Transport Protocol (SRTP) for encryption. ZRTP stands for "Zimmermann Real-time Transport Protocol" and was developed by Silent Circle's own, Phil Zimmermann.

ZRTP is key exchange protocol designed to enable VoIP devices to agree keys for encrypting media streams (voice or video) using SRTP. ZRTP is defined in an Internet draft http://tools.ietf.org/html/draft-zimmermann-avt-zrtp. The authors of ZRTP describe it as "Media Path Key Agreement for Secure RTP". This means that the ZRTP end points use the media stream rather than the signaling stream to establish the SRTP encryption keys. Many other key exchange protocols use the signaling stream (for example SIP or H.323) for media key exchange. The disadvantage of this approach is that the key exchange is visible to any intermediate device that processes the signaling stream.

ZRTP's use of the media path for key agreement ensures that media keys are agreed directly between the caller and call recipient and those keys are not visible to any intermediate signaling device. This makes ZRTP an ideal choice for use on networks where signaling is processed by intermediate devices and where it is important to ensure call confidentiality (http://www.voip-info.org/wiki/view/ZRTP).

Figure 2 shows the communication and response schematic sequence of the proposed tele-guidance system. As shown in the figure, there are three interaction objects i.e. VIP, Server, and Remote Caregiver that describe how and in what order objects/components of system work together and how tasks are moved between them.

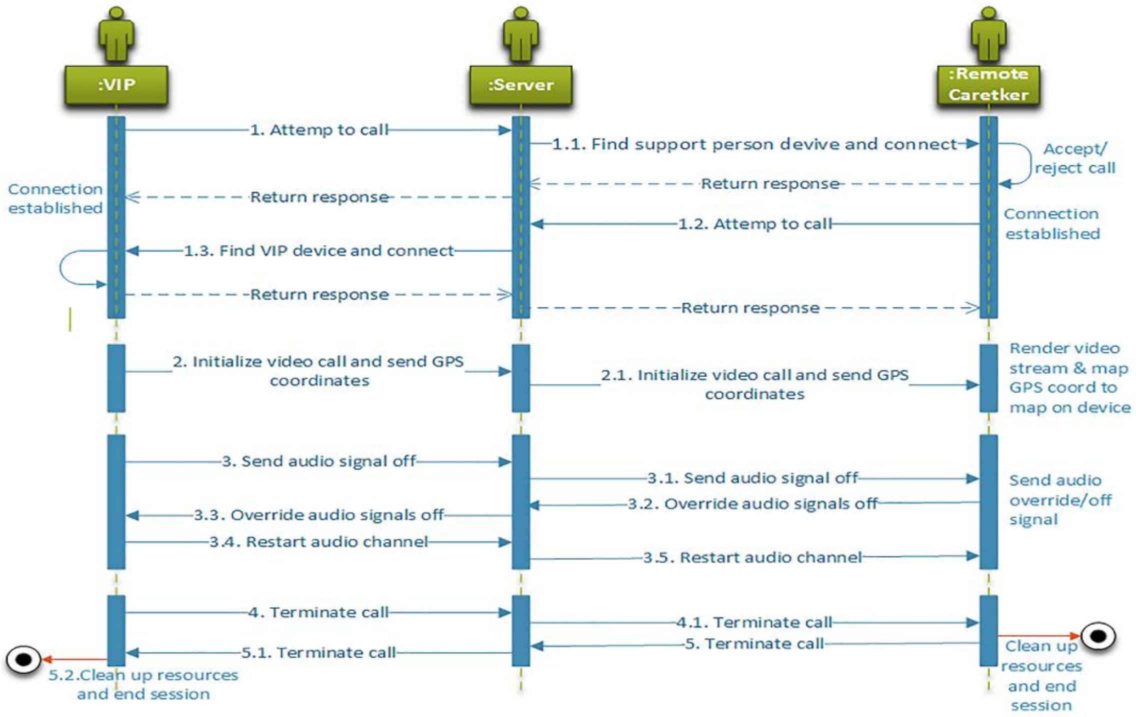

Figure 2. *The communication and response schematic*

3. USABILITY TESTING

The main objective of conducting usability experiments is to remove problematic issues from assisting users to navigate them through proposed tele-guidance system and identify the flaws that have been hidden through the development process from developer's point of view. Analyzing tasks of usability test facilitates designing system's concept more accurately. In order to organize usability testing before conducting it, a set of assumptions should be predefined, and then assumption should be evaluated after the usability testing. There should be 4 to 6 participants in usability testing to rely on results; a final report should outline findings and provide developers with recommendations to redesign the system. (Donahue, Weinschenk and Nowicki, 1999, Nielsen, 1994, Jeng, 2005, Sauro and Kindlund, 2005).

Proc. 11th Intl Conf. Disability, Virtual Reality & Associated Technologies
Los Angeles, California, USA, 20–22 Sept. 2016
©2016 ICDVRAT; ISBN 978-0-7049-1547-3

3.1 Test scenarios

Test subjects in all experiments will be real VIP; fully blind or near blind. In future, we are potentially interested to support deaf-blind persons too as well though it requires further modalities to be added to the tele-guidance system.

Test scenarios for VIP:

- *1st phase:* VIP user initiated a tele-guidance session and followed voice and haptics/vibrations based instructions of the remote caregiver for navigation successfully.
- *2nd phase:* User muted the voice.

Test scenarios for remote caregiver:

- *1st phase:* The remote caregiver received a tele-guidance call from the VIP and guided her through voice and haptics/vibration based instructions to navigate successfully.
- *2nd phase:* Remote caregiver gets indication that VIP muted the voice channel.
- *Test case:* Remote caregiver overrides the muted voice channel.

3.2 Usability matrices

The specified usability metrics will be used to evaluate the results of all tests. The metrics will define all experiment settings for a given test e.g. detail of paths, hazards on the way, muting of voice commands from remote caregiver, and success/fail condition. The results will help to investigate effectiveness, efficacy, satisfaction, and learnability of the system. These categories will be measured by the percent they complete the task, how long it takes to complete the tasks, ratios of success to failure to complete the tasks, time spent on errors, the number of errors, rating scale of satisfactions, number of times user seems frustrated, etc. Additional observations of the users give designers insight on navigation difficulties, controls, conceptual models, etc. The ultimate goal of analyzing these metrics is to find/create a prototype design that users like and use to successfully perform given tasks (Wickens, 1992) (Kuniavsky, 2003).

4. ATTITUDE OF VIP AND BLIND PERSONS TOWARDS NAVIGATION ASSISTANCE

As previous studies have indicated, assistive tools have acceptance issues by VIP. The thresholds for accepting and starting the use of assistive tools have number of potential reasons related to either assistive tool or user (Nordqvist, 2003, Ravneberg, 2009, Salminen, 2003). Tool-related reasons include accessibility, usability, safety, and appearance of the tool (Wickens, 1992, Nordqvist, 2003). Whereas user-related reasons include user’s previous experiences and attitude for technology, technological prowess and perceived need for the tool. Also if the assistive tool marks the user as different may cause rejection (Salminen, 2003, Söderström & Ytterhus, 2010).

This study uses an extended version of Unified Theory of Acceptance and Use of Technology (UTAUT2), which is designed for consumer acceptance context. This model can be used by organizations to gain knowledge on improving the design and marketing of their consumer product (Venkatesh, Morris, Davis and Davis, 2003). The question set was modified to suit the VIP [APPENDIX A]. The UTAUT2 model constructs are performance expectancy (PE), effort expectancy (EE), social influence (SI), facilitating conditions (FC), hedonic motivation (HM), price value (PV) and habit (HA) (Venkatesh, Morris, Davis and Davis, 2003). The constructs are moderated also by age and gender (Venkatesh, Morris, Davis and Davis, 2003) which are asked by background questions (BG). Because the questionnaire is about assistive tools and for special group, we felt that some original UTAUT (Venkatesh, Thong, and Xu, 2012) questions should be included, especially from group of anxiety (ANX) and attitude (ATT), which had been dropped from the UTAUT2 model.

In addition, groups of questions not related to technology acceptance were included. The questions suit especially for tele-guidance tool design. These include questions assessing the potential for specific assistive technologies for the purposes of developing prototypes (SPE). The prototypes include tele-guidance system with location finding functionality. Also questions on willingness to adapt new technologies (TA) of visually impaired and previous experience (PEx) of using navigation assistance, on support persons (SP) availability, habits, and willingness to change routines or practices (RO), and whether there are independency and privacy issues (IP), were included.

The questionnaire is divided into two parts, the first being a semi-structured interview set of 10 premade questions and few possible follow-up questions (question numbers 1-10), and the second part consists of 26 statements which are to be answered with 5 point Likert scale (question numbers 11-36).

4.1 Details of the study

4.1.1 Participants and findings based on background questions. The number of participants was 19. Their ages varied (19-82 years) and they were in all planned age groups (i.e. 18-39, 40-64, 65-above) and sexes (Male and Female). Within the youngest and oldest age group, women seemed to be more interested in participating in this study while men dominate the middle age, Figure 3. The level of vision varied from total blindness to low vision. Figure 4 illustrates that there are more VIP who have lost their vision gradually as been born VIP. There is not great difference between sexes.

Approx. half of the participants were smartphone users. The eldest age group was using least of navigation assistance. Figure 5 shows how the different age groups own and use mobile devices. The “yes” circle demonstrates the percentages of participants using mobile device by each age group. And “no” circle demonstrates the exactly the same on not using. The youngest age group is most keen on using mobile devices in contras of the eldest who are not that interested using them.

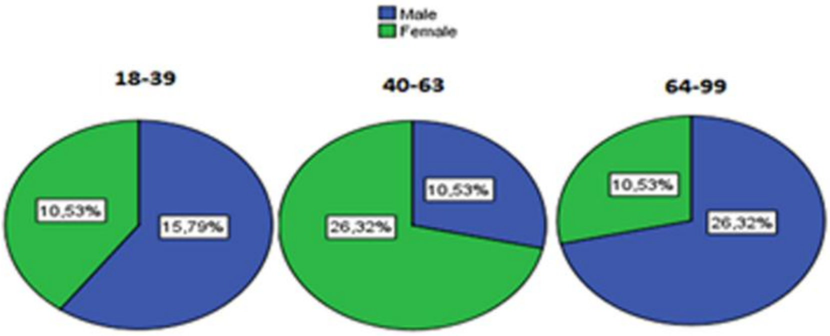

Figure 3. *Percentage of male-female participants by age group*

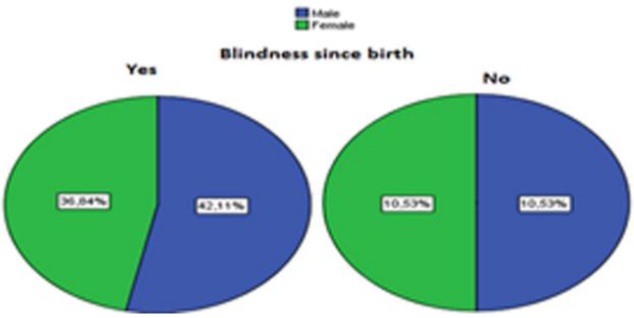

Figure 4. *Percentage of male-female participant’s blindness since birth*

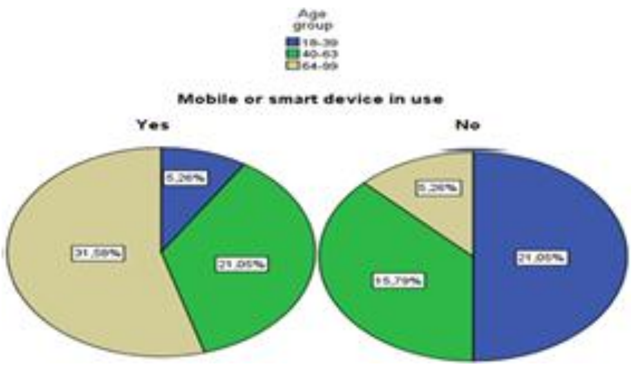

Figure 5. *Percentage of mobile or smart device users by different age group.*

4.1.2 Analysis methods. Mixed methods was used as research method for this study. Both numeric and narrative data were collected. Quantitative data was analyzed first, that provided a good background for qualitative analysis. Though as number of participants was low i.e. 19, the statistical results are directive. The statistical analysis was done through SPSS program. The data was analyzed with regression test, variance tests, and non-parametric tests. The statistical tests were done with 3 background variables: gender, age, and age group.

Regression analysis is meant to find out linear dependency of two variables. Variables included were age, gender, age group and UTAUT2-model constructs. Cross-tabulation is used to find connection between two variables. The connections were investigated between attitude and gender, age or age group. Variance analysis is conducted on the material. Factor analysis is meant for describing same phenomenon on fewer dimensions: In other words, to compress the information. This would make the interpretation of the factors easier.

The qualitative data amount was not huge as the questionnaire served mainly the quantitative aspect of the research. The qualitative analysis was two-phased. In the first phase the questions were sorted on how they may give answers to the selected topics. For example for finding out "Technological adaption" questions 6, 8, 31, 32, 35 and 36 were picked. The second phase was used to check whether any data were missing. A simple keyword list was considered at first but the qualitative data material amount was small so the list was abandoned. Each interview was transcribed and those parts containing answers to different categories were easily found even without the keyword list.

4.1.3 Analysis and discussion. The data set collected through modified UTAUT2 – model questionnaire was used to measure if UTAUT2 acceptance model is usable when assistive technology for VIP is studied. The questionnaire is meant to measure UTAUT2-model variables. If the questions are created in a way that they measure each variable, then factors can be derived from the answers. Factors can be then analyzed further. If the internal consistency is high among the answers, the model is suitable for this kind of study. When the internal consistency is low, it is a sign that the questions don't measure the phenomenon at hand (in this case a UTAUT2-model variables).

The UTAUT2-model variables are factored by Varimax-Rotation method. The internal consistency has been checked for each variable. Further tests have been made for each variable included in a factor and which support the UTAUT2 model. Factors are scrutinized by factor loadings, commonalities and Cronbach's alpha.

Figure 6 shows how UTAUT2 -model is usable for studying acceptance issues by VIP. Middle row presents the UTAUT2 constructs and bottom row presents the questions which measure these constructs. UTAUT2-model variable "Social Influence" is measured by three questions. The analyzed results indicate that these questions do not measure the variable, because the three questions and answers do not load on the same factors and their internal consistency is low: The Cronbach's alpha is negative (-0.31). This means that this data do not support that UTAUT2-model variable. The same goes with construct "Facilitating Conditions" with low Cronbach's alpha (0.11) showing there is no internal consistency between the variables. Other variables than the mentioned two support the UTAUT2-model when scrutinizing Cronbach's alpha value.

4.1.4 Conclusion. As a result, it seems that the model is usable for this kind of research. Nevertheless, some questions don't support or measure given variable. Some questions should be considered and tested again. Consideration here may mean that the Finnish translation of the questions could be adjusted. Or maybe, in retrospect, the removing few of the UTAUT2 questionnaire statements aside could have been an error. This was done to shorten the interview duration. Also some of the UTAUT2 questions were hard to modify to suit for this special purpose, the assistive navigation tools for VIP. As a conclusion for quantitative analysis, it can be said that men and women react differently for technological assistance tools. Women do have more negative attitudes towards technology than men, Figure 7.

5. CONCLUSIONS

In this article, a tele-guidance based navigation assistance system to assist VIP in navigation was presented. The approach of the system is based on the idea that a blind pedestrian can be assisted by spoken instructions from a remote caregiver who receives a video stream from a camera carried by the visually impaired user. Different usability testing phases of the system were described. The scenarios for the testing of overall system for both VIP and remote caregiver to evaluate the usability factors of the system in each of its testing phases were specified. We expect that participants could complete their tasks with the help of the proposed system. Task accomplishment could fulfil expected efficacy and effectiveness of system. Results of the usability test will provide with actionable suggestion to increase usability of the proposed tele-guidance system.

A qualitative study using a modified questionnaire based on Unified Theory of Acceptance and use of Technology (UTAUT) to study attitudes of VIP towards navigation tools (technological & non- technological) was also reported in the article. As a conclusion for the qualitative study, it can be said that VIP in general have an interest towards technology and new kind of assistive tools. Unfortunately the participants have not found much navigation assistance devices suitable to their tastes. This means that the VIP should be taken into design process. Technology may increase the acceptance in the future, but so far it has not been the case. Furthermore, every-day mobile technology is already becoming common among VIP's and applications for those devices can be designed. Advantages of mobile applications include non-stigmatization and affordability. Many of the VIP are used to white canes, and also for the cane's extra function as the signal cane. Therefore creating light weight, low-price extra-functions for the cane is a good idea. Especially there is a need to encourage elderly VIP to acquire and use assistive tools.

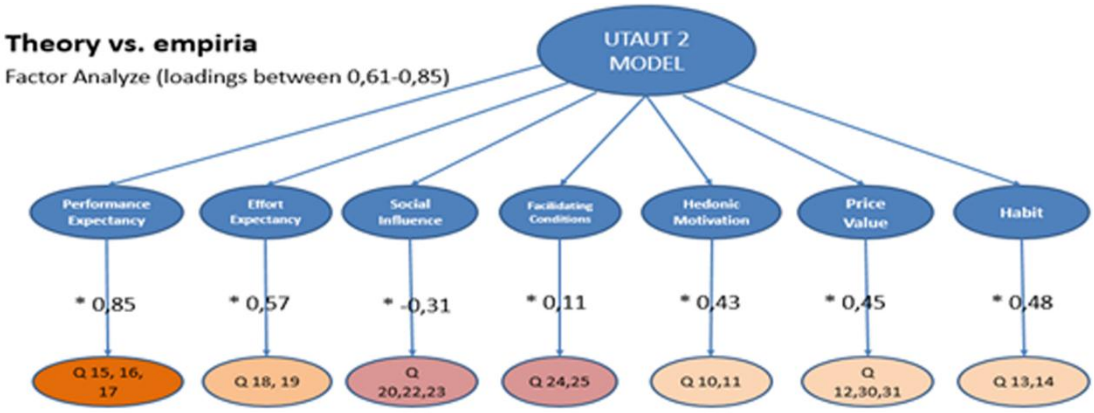

Figure 6. *The analyzed UTAUT2 constructs.*

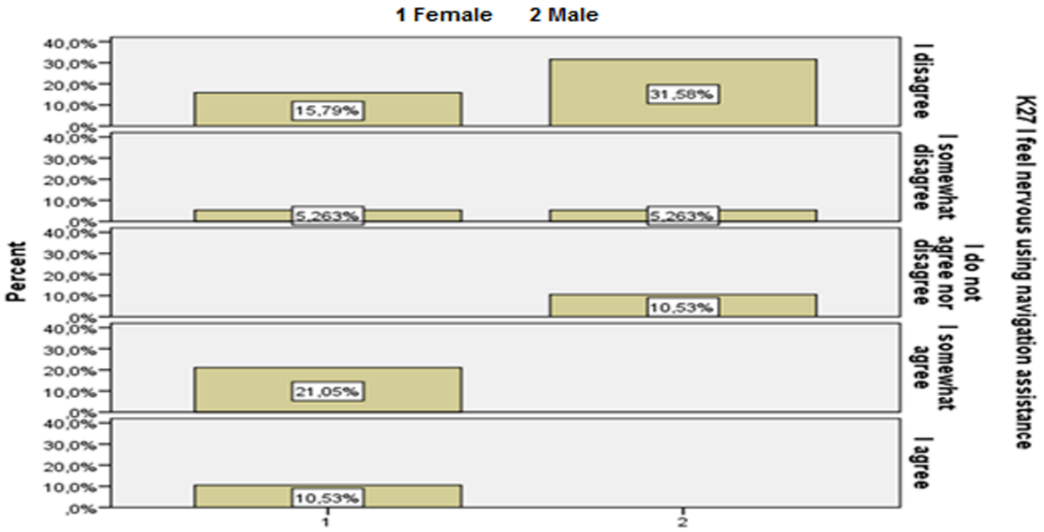

Figure 7. *Nervousness towards navigation assistance by gender*.

Acknowledgements: This paper has been written as part of the ASTS (Assisted Living for Senior Citizens) Project funded by Academy of Finland and Japan Science technology Agency (JST).

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APPENDIX A

The Questionnaire with UTAUT Constructs		
Serial #	**Construct**	**Questions**
1	BG	Age
2	BG	Gender
3	BG	Did you acquire visual impairment with birth or did you lost vision? How long ago?
4	BG	What is your visual acuity?
5	SP	Do you have a support person(s) whom you can contact when you need help? Which hours available?
6	PEx, TA	Do you use smartphone or any other mobile device? What brand? Which apps?
7	PEx	Do you use white cane? When / why did you start using it?
8	PEx, TA	Have you used any other navigation assistance? Did you stop using it? Why?
9	PEx, RO, IP	In what situations do you use navigation assistance?
10		Have you used navigation assistance tools previously? Why did you quit?
Statements		
11	HM	Navigation assistance makes going outdoors more pleasant.
12	HM	I like using navigation assistance.
13	PV	Navigation assistance tools are reasonably priced.
14	HA	Using navigation assistance has become a habit to me.
15	PE	I need navigation assistance every time I go outdoors.
16	PE	In my opinion navigation assistance is useful when I am outdoors.
17	PE	Navigation assistance increases the speed of doing chores.
18	PE	If I use navigation assistance, I will increase my chances to get where I want.
19	EE	I find navigation assistance tools easy to use.
20	EE	Learning to use navigation assistance tools is easy for me.
21	SI	People, who are important to me, think that I should use navigation assistance.
22	IP	I find it annoying when surrounding people notice I am visually impaired.
23	SI	The society has been supportive in the use of assistive
24	SI	Instructors or medical staff have been supportive in the use of assistive
25	FC	My knowledge of using navigation assistance is sufficient.
26	FC	If I have problem navigation assistance, I know from who I ask help.
27	ANX	I feel nervous using navigation assistance.
28	ANX	Navigation assistance is somewhat intimidating.
29	ATT	Using navigation assistance is a good idea.
30	ATT	Navigation assistance makes me feel safe.
31	PV	I am willing to spend money in order to buy new navigation assistance.
32	PV, RO	I am willing to spend my time in order to learn to use new navigation assistance.
33	RO	I am willing to change my daily routines, if I receive a new kind of navigation assistance.
34	33	I think that people close to me are willing to change their daily routines, if I receive a new kind of navigation assistance.
35	IP, SPE	It is good that people close to me know my location.
36	IP, SPE	I would like to select when people close to me know my location.

Computer model based audio and its influence on blind students' learning about gas particle behavior

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ABSTRACT

This paper focuses on the need of students who are blind to access science curriculum learning materials. Net Logo is a widely used computational agent-based modelling language that enables exploring and constructing models of complex systems. The Listen-to-Complexity environment is based on Net Logo and involves sonified feedback that was adapted to users who are blind. This study examines the scientific conceptual knowledge, systems reasoning, and Kinetic Molecular Theory of gas in chemistry that were learned as a result of interaction with the Listen-to-Complexity environment by people who are blind as shown in their answers to a pre- and post-test. Five participants who are blind volunteered to participate in this research. The preliminary findings are encouraging with regard to the sonified model's efficacy in providing access to central and difficult scientific concepts, even when the target phenomenon is complex. The benefits of this longitudinal research are likely to have an impact on science education for students who are blind, supporting their inclusion in the K-12 academic curriculum on an equal basis with sighted users.

1. INTRODUCTION

Students who are blind have been integrated into public schools and are required to complete the same curriculum and examinations as their sighted peers. However, they are blocked from access to firsthand information because many education-learning resources, especially in the science fields, are based on the visual mode, which employs diagrams, charts, models, and exploration in science laboratories (Beck-Winchatz and Riccobono, 2008). In their learning process, people who are blind gather information through perceptual and conceptual tools (Passini and Proulx, 1988). At the perceptual level, haptic, auditory, and olfactory senses compensate for the shortage of visual information. Technology learning systems developed to support Science, Technology, Engineering, and Mathematics (STEM) education among students who are blind are scarce. They include the Talking Tactile Tablets (Landau, Russell, Erin, and Gourgey, 2003), which are based on audio and 2D tactile materials and support interaction with 2D images for learning mathematical and science diagrams. The Line Graphs technology is based on auditory and haptic feedback and is geared to learning mathematics (Ramloll, Brewster, and Burton, 2000).

Agent-based modeling is a computational modeling paradigm that simulates complex dynamic systems by simulating each of their many autonomous and interacting elements. The NetLogo (Wilensky, 1999; Levy and Wilensky, 2004) modelling platform is based on previous research into learning about complex systems using models with sighted students (Levy and Wilensky, 2009a, 2009b). The current paper delves into issues of auditory perception that accesses such dynamic information through multiple parallel representations. The Listening to Complexity (L2C) system is based on the principle of perceptual compensation using technologies (Lahav and Levy, 2010; Levy and Lahav, 2011). L2C harnesses the auditory mode to transmit dynamic complex information. The choice of an auditory display results from three considerations: (a) the auditory mode transmits information that changes both in space and time, like the visual mode and unlike the haptic mode; (b) the auditory mode easily interfaces with large bandwidths at fine frequency-discrimination and intensity-discrimination thresholds (Capelle Trullemans, Arno, and Veraart, 1998); (c) the auditory system is used to deal with complex and rapidly changing sound patterns (Hirsh, 1988). Research into the impact of different components of sound on auditory perception has shown that increasing the number of channels beyond three causes degradation in comprehension (Stifelman, 1994) and that a greater frequency separation between sound streams results in better stream segregation (Bregman, 1990).

In the current research, we use sound to represent a dynamic rather than a static array. The referents of the dynamic representation are multiple and operate at two system levels. Going beyond established research, we explore how a combination of several factors may impact auditory perception of sound. This study continues to explore auditory compensation for visual information among students who are blind and also looks at perception of dynamic and complex displays and learning about dynamic complex systems.

The learning system that is used in this research is based on transmittal of visual information of dynamic and complex systems, providing perceptual compensation by harnessing auditory feedback. The feedback consists of sonification of variables: wall hits (represented by the sound of a bat hitting a baseball), particle collisions (represented in the L2C system by the sound of two billiard balls colliding), announcement of particle addition, and events that are registered as sounds on an audiograph: velocity (telephone-dash speed), temperature, pressure, and volume. The agent-based NetLogo computer model of gas in a container is used to convey information regarding both individual gas particles, such as particle collisions, a particle hitting the wall of the container, and system wide phenomena, for example, pressure, using alerts, object and status indicators, data representation, and spatial audio displays (Figure 1). In the figure, the square on the right represents a container and the dots inside represent the gas particles. The particle surrounded by a circle represents the observed particles. This research improved the understanding of the processes through which perception of sound takes place and transforms into conceptual change through interactions with dynamic complex systems. It also examined the ability to access science information through a sonified learning system and its effect on learning and the understanding of complex systems among people who are blind.

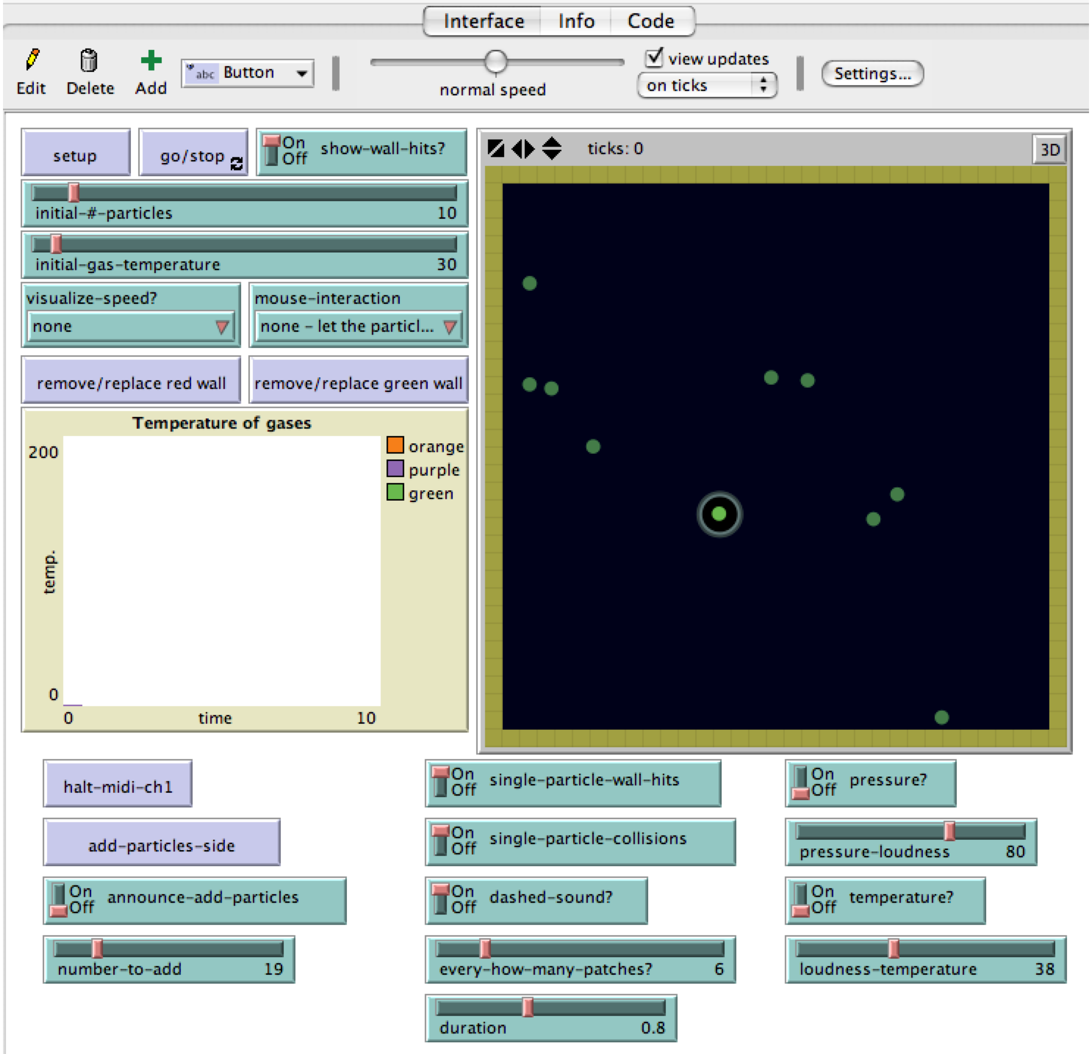

Figure 1. *L2C sonified model of gas particles in a container. Bottom-right are variables and events that relate to a single focal particle. Bottom-middle are variables and events that relate to the group of particles.*

2. METHOD

2.1 Participants

This research studied five participants who are blind who worked with the sonified curriculum and were observed individually. They all have the ability to use computers for daily use.

2.2 Instrumentation

The research included one implementation tool and three data collection tools, described below:

L2C learning materials with sonified model. The learning materials are based mainly on Chapter 1 of the Connected Chemistry curriculum (CC1) (Wilensky, 1999). The L2C sonified model is based mainly on this chapter, which involved 62 open-ended questions and 144 multiple-choice questions. This chapter included seven activities: what is a model?, the computerized model, kinetic molecular theory, pressure, changing pressure, diffusion;, and atmospheric pressure and gravitational force. The original curriculum was developed based on CC1 by Samon, Peleg, and Levy (2014). This curriculum has been rewritten adaptively to the target population by the researcher, using the universal design learning methodology (CAST, 2011). For example, some images were described in words and others were tactile printed. This curriculum was available to the participants as text-to-speech file and in Braille, and in both representations the images were presented as tactile images. All images were printed in a Swell-Form Graphics Machine (a fuser) manufactured by Zychem using a standard print on Swell-Touch paper and running this paper through the Swell-Form Graphics Machine. The heat from the machine reacts with the black ink and causes it to "swell", creating the tactile image. Participants were able to read or listen to the files and to explore the tactile images that were embedded in the text. In addition, instructions on how to run the computer model and which variables to activate preceded each computer task. It would be preferable if the participant were able to operate the computer model independently. Unfortunately, in this version the participant was unable to do so and needed the researcher to operate the computer model for the participant. We hope that next version will allow the user to activate the L2C independently.

Background questionnaire. This questionnaire included personal information, science education, and computer technology use.

Pre- and post-test questionnaires. The pre- and post-test questionnaires included assessment of the learners' understanding of the gas laws and kinetic molecular theory, were identical, and contained both open-ended questions (three questions) and multiple-choice questions (22 questions). Most items were a subset of those that have been previously developed (Levy and Wilensky, 2009b). The pre- and post-test questionnaires were rewritten for the target population using the universal design learning methodology (CAST, 2011).

Research protocol. A research protocol was developed and contained the research activities from the ten sessions: introduction; pretest questionnaire; learning intervention using the L2C learning materials with sonified model; and post-test questionnaire.

2.3 Data Analysis

Quantitative analysis was based on previously developed coding schemes. The participants' answers to the pre- and post-test questionnaires and to the L2C learning materials with sonified model questions were transcribed and coded for conceptual understanding and reasoning in terms of complex systems. The data analyses were consistent with previously developed coding schemes (Lahav and Levy, 2010). Data analyses were based on participants' verbal answers to the questions presented in the questionnaires and activities. These answers were coded for the dependent variables: scientific conceptual knowledge and systems reasoning. With respect to scientific conceptual knowledge, questions were coded based on previous coding of the same questions (Levy and Wilensky, 2009b; Samon and Levy, 2013). Multiple-choice questions were coded as correct or incorrect, and open questions were coded for the relevant correct scientific principles they included. For systems reasoning, the open questions were coded based on three central components (Wilensky and Resnick, 1999; Jacobson, 2001) that described the structure of the explanation. For the pre- and post-test, descriptive statistics were compared, and progressions of frequencies were computed and related to the activity. The quantitative analysis used statistical software such as Excel and SPSS, according to participants' answers to the pre- and post-test.

2.4 Procedure

All participants worked and were observed individually. Each session lasted 60 minutes, and the research consisted of 10 sessions that were distributed over 5-8 weeks. Identical pre- and post-test questionnaires were used to assess learning and answers throughout the activity. No feedback was provided on performance at any stage.

3. RESULTS

It was found that participants' score for the pre- and post-test questionnaires rose from 54.2% to 76.7%, a statistically significant difference. A more discriminate analysis shows that in the multiple-choice questions, participants' score for the pretest and post-test questionnaires rose from 50% to 70%. The open-ended questions included three topics: diffusion, atmospheric pressure and gravitational force, and changing pressure (Table 1).

Table 1. *Comparison of participant knowledge in the pre- and post-test.*

	Open-ended questions 15%			Multiple-choice questions 85%	Mark 100%
	Diffusion	Atmospheric pressure and gravitational force	Changing pressure		
Pre-test	2.1%	1%	1.1%	50%	*54.2%
Post-test	2.7%	2.3%	1.7%	70%	*76.7%

*p<0.01

On an overall average for the open-ended questions, participants' score rose from 26% in the pretest to 46% in the post-test (Figure 2).

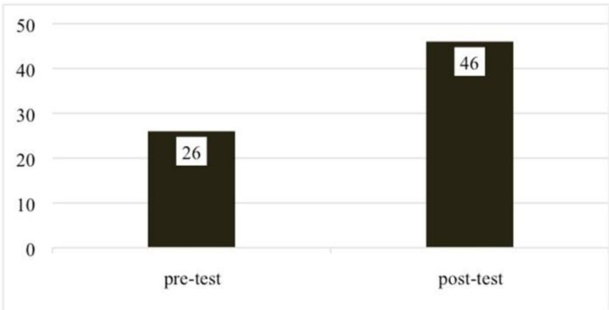

Figure 2. *The open-ended questions in the pre- and post-test.*

Test questions were divided according to three levels of difficulty (1 easy, 2 medium, 3 difficult), and the first-level test score rose overall from 60% in the pre-test to 86% in the post-test. The intermediate level score increased from 52% to 91%, and the difficulty level increased from 50% to 85%, as shown in Table 2.

Table 2. *Participants average in pre- and post-test by difficulty in percent.*

Difficulty	Pretest	Post-test
Level 1	60	86
Level 2	52	91
Level 3	50	85

In further analysis of the answers to test questions, across the seven educational activities of the unit, participants were found to have a significant increase in grade for all subjects in each of the activities. Figure 3 presents the pre- and post-test grade details in the seven activities.

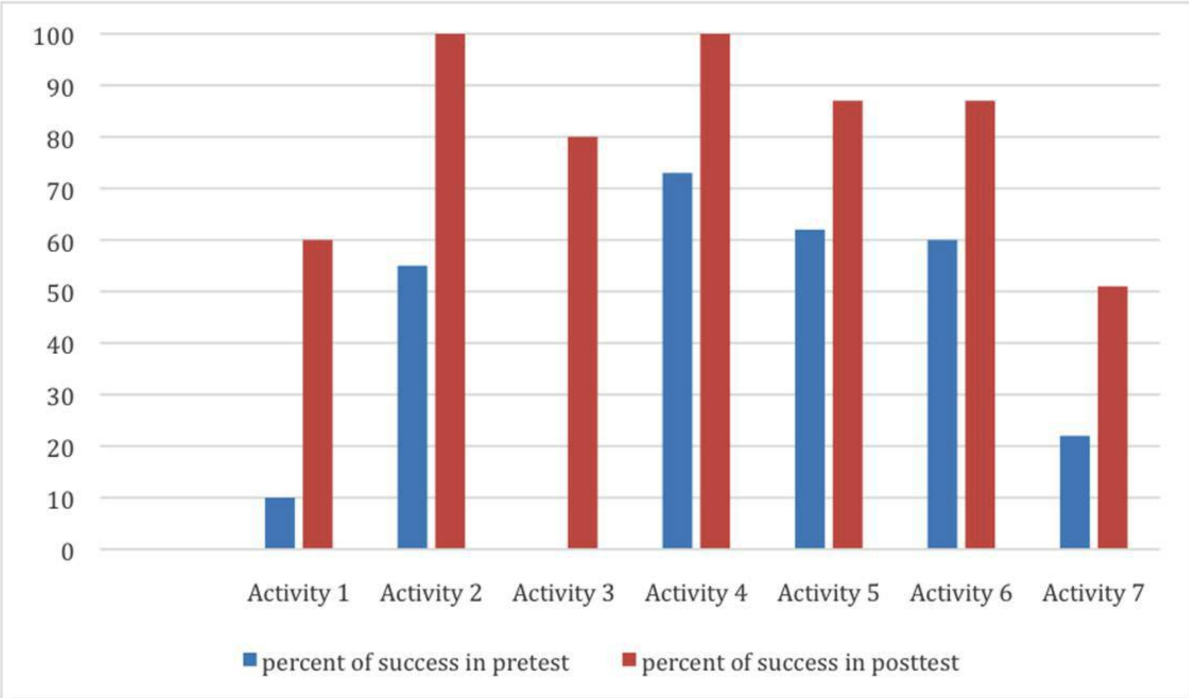

Figure 3. *Participants average in pre- and post-test by activities.*

4. CONCLUSIONS

The preliminary findings are encouraging with regard to the sonified model's efficacy in providing access to central and difficult scientific concepts, even when the target phenomenon is complex. The study results express the high-level ability of the participants to learn STEM material with a complex dynamic model using sonification feedback.

Besides the cognitive learning performances, all learning activities were based on complex sonified information and included four to five types of different sonification feedback that were played at the same time, for example, during the activities: pressure macroscopic and microscopic concepts, changing pressure, diffusion, and atmospheric pressure and gravitational force. In these activities the participants were required to listen simultaneously, using the model, to particles colliding with each other, particles colliding with the wall, adding particles, pressure, temperature, and speed. By means of this special auditory and cognitive capability of the software, the participants succeeded in the learning activities and improved their knowledge in the post-test questionnaire.

The type of question had minor effect on the participants' success. There was only a small difference in the participants' answers to the open-ended questions compared to the multiple-choice questions. The type of learning activities questions on the pretest questionnaire had almost the same percentage of success, but higher differences were found in the post-test questionnaire. For all seven activities, higher grades were found in the post-test questionnaire at all three levels of difficulty.

The results of this study have important implications for the continuation of the research and also for its implementation. Additional research is needed to compare the effectiveness of an accessible learning curricular textbook integrated with a sonified NetLogo model learning environment versus an accessible learning curricular textbook alone. This research should explore the benefits of learning with L2C relative to learning through standard learning materials among students who are blind.

The long-term practical benefits of this research are likely to have an impact on STEM education for students who are blind, as equal access to low-cost learning environments that are equivalent to those used by sighted users would support their inclusion in the K-12 academic curriculum.

Acknowledgments: This research was supported by a grant from The Israel Science Foundation (ISF) (Grant No. 0607015102). We thank our anonymous participants for their time, efforts, and ideas.

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Visual impairment simulator for auditing and design

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ABSTRACT

Individuals within the visually impaired community often have difficulty navigating environments due to the different ways in which they view the world, with even apparently simplistic locations frequently being challenging to traverse. It is therefore important when designing architecture or environments, to take into account the perspectives of people with visual impairments in order to ensure that design outcomes are inclusive and accessible for all. Although there is documentation regarding guidance and procedures for design of inclusive spaces; architects, designers, and accessibility auditors often find it hard to empathize with visually impaired people. This project aims to make the process of inclusive design easier through the development of a mobile app, VISAD (Visual Impairment Simulator for Auditing and Design), which enables users to capture images or import CAD designs and apply image distortion techniques in order to replicate different visual impairments.

1. INTRODUCTION

There are 2 million people living with some form of visual impairment in the UK alone (RNIB/Access Economics, 2009) including 218,000 people registered with a severe visual impairment or blindness (RNIB/Access Economics, 2009). The number of people living with a sight threatening eye condition has been predicted to rise over the next decade (Minassian and Reidy, 2009), and it is therefore becoming increasingly important to emphasize inclusive design when producing new products and services, ensuring that they are accessible to, and useable by, as many people as reasonably possible (Clarkson and Coleman, 2015).

Architectural design is a key area of interest when it comes to design accessibility. This is especially true for public areas, which often have to abide by various codes of practice, and legislation. There is ample documentation available on the subject of disability access. However, although these documents provide useful information about specific individual architectural aspects, for example, the number of steps in a staircase before a landing, they do not provide the reader with a sense of what it is like to be afflicted with a visual impairment.

Simulating visual impairments is arguably the most effective way to educate uninformed designers about how a person with a visual impairment perceives their environment. Allowing architects to 'see' through the eyes of a visually impaired person makes it much easier for them to empathize with the difficulties individuals might face, and provides them with a greater understanding of the aspects of architecture which can be problematic for people who have visual impairments. Prior research, and subsequent software solutions, related to simulating visual impairments have been predominantly developed on non-mobile PC platforms. This project aims to improve upon, and enhance previous attempts at simulating visual impairments by developing a visual impairment simulator, VISAD, (Visual Impairment Simulator for Auditing and Design) that runs on mobile devices such as smartphones and tablets enabling both in the field simulation as well as the ability to import images at the design stage.

2. INFLUENCES FROM PREVIOUS STUDIES

Early research in this field includes that of Fine and Rubin (1999) who printed black circles on clear acetate film using an inkjet printer to replicate a scotoma. Test subjects read text through the acetate film, and changes in reading performance were documented. Recent research projects have become increasingly sophisticated with most involving the use of computer graphics and image processing techniques to distort images in various ways to replicate visual impairments.

Research by Hogervorst and van Damme (2006), involved the production of a software system that allowed the user to import an image and apply simulations of cataract, macular degeneration, glaucoma, retinopathy, myopia, and hyperopia to a 2D image in order to educate and give users an insight into the problems that people with visual impairment conditions faced. Their research provided an in depth perspective on the methods that could be applied to produce visual impairment simulations including a demonstration of how light glare can effect certain impairments.

Banks and McCrindle (2008) also investigated the use of image processing techniques to replicate the characteristics of common visual impairments in order to provide planners, designers, and architects with visual representations of how people with visual impairments viewed their environment, leading to increased accessibility in the built environment. This research also provided insight into the types of features that could be added to a proposed solution including the ability to import images from CAD files into the system.

In addition to 2D image processing solutions, a research project carried out by Lewis, Shires, and Brown (2012) involved the application of real time, simulated visual impairments to a virtual 3D environment. This project utilized the Microsoft XNA video game development framework, and allowed the user to walk around a 3D office environment while being afflicted with different visual impairments. This project showed how virtual and real time augmented reality can be used to enhance user experience.

The inclusive design toolkit, developed at Cambridge University, by the Engineering Design Centre (EDC, 2016), features a set of tools that aid creation of products and services that are inclusive or accessible. One such tool is the 'Vision Simulator' which provides examples of visual impairments applied to a selection of images. The simulator features a variety of impairments that can be applied with different levels of severity. It also includes a section which demonstrates impairments in relation to different objects, including a railway ticket machine and a household toaster. These simulations allow the user to alter certain design aspects of the objects (mainly the colours used) to show how small changes in some of their characteristics can alter their accessibility to someone with a visual impairment. The inclusive design toolkit demonstrates good practices regarding how the user interacts with the system, providing an easy-to-use and intuitive GUI (Graphical User Interface) that incorporates a number of visual impairment presets alongside slider controls for the severity of the impairment. The system also provides users with a short description of the visual impairment being simulated and the demographic of people affected by it.

'Project Rainbow' at the University of Reading (Bright and Cook, 1999), investigated the effects that colour and luminance have on the built environment, when viewed by a visually impaired person. The outcome of this project was a set of advisory papers and design guides which provide guidelines and rules to follow when designing the interiors of buildings. The overall aim was to create designs that were accessible to visually impaired people, but also acceptable for 'designers and fully sighted users of the building'.

ViaOpta (2016) is one of the first apps to be developed for mobile platforms, however whilst providing a useful tool for simulation of visual impairments in real-time, it falls short with regards to its flexibility to import and export images and simulations.

3. DEVELOPMENT ETHOS AND IMPLEMENTATION APPROACH

3.1 Development Ethos

One aspect that many earlier research projects have in common, is that they were designed to run on non-mobile PC platforms. Whilst this approach has benefits such as increased processing power and greater standardization in terms of OS (operating system), mobile device platforms offer greater flexibility of use for architects, designers, and accessibility auditors during the inclusive design, and auditing phases of their projects. Additionally, whilst mobile devices have become incredibly popular over the past decade, for example, by 2013 there were 900 million devices running Google's Android OS (Business Insider, 2013), PC sales have declined substantially (Gartner 2016), and hence it is timely to develop for the mobile market.

The VISAD application has therefore been developed for use on smartphones or tablets, allowing the user to capture images with the device, and then create instantaneous visual impairment simulations of the images providing users with a better understanding of problems that might occur for people with visual impairments. The app handles all image capturing aspects of the simulation within the app, so that it is convenient to use. The app can produce a series of preset visual impairment simulations as well as allowing for customization of the various image processing effects that are used to take into account severity and layering of conditions. It also provides the user with information regarding specific impairments, including the demographic that is most commonly afflicted. Other key features implemented include the ability for the app to import image files from a range of sources as well as through the integrated camera and the facility to save and export generated image files for external use via their associated Google Drive cloud storage.

3.2 Implementation

VISAD has been developed for the Android OS platform, implemented in the Java programming language, and created using the Android SDK version of the Eclipse IDE (Google Android, 2014a) and Android, version 5.1, API 21 – Lollipop, (Google Android, 2014b). The app operates with three main classes: the image capturing class; the GUI and user input class; and the graphics rendering class. The overall processing of the app occurs in three stages. First the user captures an image with the devices camera, or imports an existing image. The user then applies a combination of the different image effects, or selects an impairment preset. Finally, the user analyses the resultant image using the comparison tool, or the edge detection tool, and then exports the image by saving it to the devices memory.

3.3 Image Capture

The image capturing aspect of the app is implemented using the Android ‘Camera’ class. This provides access to the device’s camera in order to capture images or video, and to retrieve the relevant hardware information. It also provides handlers for setting camera specific features, such as autofocus, capture resolution, and white balance. Image capturing is implemented within the ‘CameraPreview’ class of the Java project, which provides a custom ‘SurfaceView’ component that is instantiated within the main class. This ultimately enables the devices camera output to be displayed on the screen.

3.4 Image Processing

Image processing is used within the app to produce different effects that are then combined to one image to create a visual impairment simulation. This is implemented in the app through a custom ‘SurfaceView’ component which allows for custom drawing to the screen and to bitmaps. This class defines its own thread which it uses to update the custom drawing every 1/30 of a second. It receives parameters from the GUI thread and produces drawings or image manipulation based on the input. The majority of the work done within this class is produced using the Android ‘Canvas’ class, which allows for the creation of simple 2D geometry and custom brushes. All of the image processing effects have parameters that can be altered by the user. Each effect has its own menu which contains all of the GUI elements that control the parameters. These menus also include checkboxes which are used to toggle the relevant effect on or off. These parameters are passed to the rendering function and effect what is drawn in the frame. The different effects implemented include:

3.4.1 Brightness. Altering the brightness of the image involves altering the RGB values of the individual pixels in the image. This effect uses the Android Bitmap class to get the pixel value at an x/y coordinate in the image, the pixel’s RGB values are then multiplied by a double value, and then set back in the image at the same x/y position. The double value is provided as a parameter and is a value in the range $0<x<2$, where any value less than 1 darkens the image, and any value greater than 1 lightens it. This effect, for example, is used in the macular degeneration simulation to increase the brightness of the image replicating the ‘washing out’ of colours that is commonly associated with this impairment.

3.4.2 Colour Filter. The colour filter effect overlays a semi-transparent colour on top of the image. This effect has been implemented using the Android Canvas to draw a rectangle with the same x and y position, and the same width and height of the image. The RGBA values of this effect can be altered to change the colour and opacity of the filter. The colour filter effect is rendered to a separate transparent bitmap, which is then drawn after the image when the rendering loop draws a frame. By implementing this effect in this manner it is easier to implement the option to enable/disable the effect. This effect is implemented in the Cataract preset, where a brownish filter is required to simulate the effect of protein clumps in the lens, which cause cloudy vision.

3.4.3 Warping. The warping effect causes the contents of the objects portrayed in the image be distorted. Areas of the image are stretched, pinched, and swirled which results in a warped image. This effect uses the JH Labs libraries to perform the warping, and the extent and size of the different kinds of warp can be altered to produce different outputs. There are three types of warping that the system can perform: pinching, twirling, and melting. The pinch warp causes the image to be warped towards the centre of the image; the swirl warp twists the image around its centre; and the melt warp applies random distortions to the image based on a turbulence value. These warping effects are created using forward pixels mapping, where the destination x,y coordinates are mapped using the source v,u coordinates. The warping effects are used during the simulation of Diabetic Retinopathy and Macular Degeneration to replicate the distortions that can occur as a result of these impairments.

3.4.4 Blur. The blur effect applies a Gaussian blur to the image. This effect uses the Android Renderscript API to process the image and produce the resultant blurred image. The Renderscript function for blurring allows parameters to be passed to it which control the extent of the blur. This effect can also produce a blur which fades in from the edges of the screen. A greyscale bitmask is produced that uses a radial gradient that fades from white to black from the centre of the image. This bitmask is then used to alpha composite the original image over the blurred image, leaving the centre more ‘in focus’ and the edges blurred. This effect can also be inverted, and positioned anywhere on the screen. This means that when inverted, the centre point of the effect is blurred, and it fades out towards the edge. The centre point can be positioned by the user by tapping on the screen, and the centre is set to the point of the tap. These specific aspects of the effect are used for the Myopia (nearsightedness) and Hyperopia (farsightedness) simulations. When selecting these simulations, the user is asked to tap on the screen the most distant point. This effect is used to simulate different aspects of blurred vision that are commonly related to Myopia, Hyperopia and Glaucoma. It can also be combined with the Double Vision effect to produce more severely blurred vision.

3.4.5 Vignette. The vignette effect adds a dark edge to the image which fades out toward the centre. This effect utilizes the Android Radial Gradient shader which allows the creation of a circular gradient which fades between multiple colours that are provided as parameters. In the case of this effect, the colours fade from a user defined colour at the edge (defaulted to black), to a completely transparent colour at the centre. The aperture of the effect is controlled by the radius parameter, which can be adjusted to increase or decrease the size of the vignette. This effect produces an image which has a border with a fading transparent centre. This effect is applied last in terms of layering the effect images onto the canvas and is used in the system to simulate the loss of peripheral vision, which is present in most of the impairments.

3.4.6 Double Vision. The double vision effect overlays a semi-transparent copy of the image on top of itself at a slight offset. By using the bitmap variable type that is available in the standard Android API, a copy of the image is made. This copy is then drawn over the original image using the Android Canvas. When drawing the copy, a parameter is passed to the function that draws the bitmap which alters the opacity at which the image is drawn at, and also the x and y position is offset from the original. The image is set to 50% opacity and is offset from the top left corner by a few pixels by default. The results of this effect makes it harder for the viewer to focus on any of the fine detail in the image. This effect is used in the Cataract, Diabetic Retinopathy, and Macular Degeneration presets to replicate some of the blurriness and fuzziness that is associated with these impairments.

3.4.7 Spots. The spots effect draws randomly generated shapes with “fuzzy” edges onto different parts of the image. This effect is produced by initially creating a grid to which a cell is randomly selected, and then adjacent cells are procedurally, randomly selected. This results in a single randomly created shape. The shape is then drawn to fit the canvas using a radial gradient to provide a faded edge. The characteristics of this effect, including: length of shape; size of cells; number of individual shapes; and colour and opacity can all be changed by altering the input parameters. This effect is used mainly in the Diabetic Retinopathy and Macular Degeneration simulations to represent areas where vision is completely lost.

3.4.8 Colour Blind. The colourblind effect changes the RGB pixel values of the image in order to simulate colourblindness. This effect can simulate the following types of colourblindness: Protanopia (red blind); Protanomaly (red weak); Deuteranopia (green blind); Deuteranomaly (green weak); Tritanopia (blue blind); Tritanomally (blue weak); Achromatopsia (monochromacy); and Achromatomaly (blue cone). The implementation of this effect is based on research by Wickline (2008), which provides the predefined values by which the RGB channels are multiplied by, and then combined to form a pixel. For example, the manipulation values for the Red channel, for the Deuteranopia form of colour blindness are: *(0.625, 0.375, 0), w*hich means that the red channel RGB components are calculated using: $R_c = (R_d * 0.625) + (G_d * 0375) + (B_d * 0)$.

3.4.9 Light Source. The Light Source effect is used to simulate the problems that excessive illumination can have on a visually impaired person. This effect creates a pseudo light source and places it on the image. This results in the colours and definition of the image to become ‘washed out’ due to the increased brightness. The light source effect is produced by creating a radial gradient using the Android RadialGradient class, decreasing the alpha values of the pixels from the centre, and then overlaying a brightened version of the image on top of itself. Essentially it produces a copy of the original image, then increases its brightness and cuts a circular section out of it. The effect then overlays this cut out section on top of the original image in the same location, and fades the edges of the circle to give it a more natural look. This effect has two parameters that can change its properties, the intensity value changes how bright the light source appears to be, and the size which alters the diameter of the effect on the image. The user can add multiple light sources to the same image accessing this feature via the effects menu of the GUI.

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4. SIMULATIONS AND TOOLS

4.1 Simulations

The effects described in Section 3 can be applied to the inputted image individually, or the user can choose from a selection of eight preset visual impairments from the presets menu. Each preset simulates a specific visual impairment as defined by the RNIB (Royal National Institute for Blind People, 2016) or the NEI (National Eye Institute, 2016) by automatically applying a combination of the individual effects. In addition to this, the user can adjust the severity of the effects using a 'severity slider', which ranges from mild to severe relating to the selected impairment as shown in Figure 1.

Figure 1. *Presets menu.*

Figure 2. *Cataract preset.*

4.1.1 Cataract. Cataracts, defined as the 'clouding' of the lens section of the eye, causing a decrease in the overall quality of vision, are usually identified by the eye turning from its natural colour, to a yellow/brown colour. This yellow/brown colour is the colour of the protein clumps, and the afflicted person's vision is usually 'stained' with this colour as if looking through a coloured filter. The preset for this visual impairment applies a number of different effects to simulate both the clouding of the eye's lens, and also to replicate the loss of peripheral vision. The main effect that is applied is the colour filter effect. A yellow/brown colour filter is placed over the entire image to simulate the lens clouding. To replicate the loss of peripheral vision, a black vignette is placed on the image, and a radial blur is applied to blur the edges of the image in a circular fashion. The brightness of the image is also decreased slightly to account for the lower amount of light able to pass through the lens (Figure 2).

Figure 3. *Glaucoma preset* .

Figure 4. *Retinopathy preset.*

4.1.2 Glaucoma. Glaucoma is a visual impairment that mainly effects the peripheral vision and if left untreated can lead to blindness. The most predominant effect that this preset applies to the image is the vignette effect. This effect is used to create a large black ring around the edges of the image, which is used to replicate a loss of peripheral vision. Also involved in this preset is a slight increase in brightness. This is used in conjunction with a moderate application of blur to simulate the mistiness and 'washed out' colour that are associated with glaucoma symptoms (Figure 3).

4.1.3 Retinopathy. Retinopathy affects people who suffer from diabetes. It is caused by microvascular changes in the retina section of the eye, and results in blurred and patchy vision, which ultimately leads to blindness. People who suffer from Retinopathy have areas of their vision which don't function correctly, this causes spots of darkness that are surrounded by blurriness. The preset which is used to simulate Retinopathy makes use of the 'Spots' effect to recreate the patchy areas of vision loss that are associated with this impairment. This is combined with a slight blur and warp effect to simulate the distortion of the vision that occurs around the areas of vison loss. When the severity of this preset is increased to +75%, a vignette is also applied to demonstrate the loss of peripheral vision that occurs in the later stages of this impairments progression (Figure 4).

Figure 5. *Pigmentosa preset.*

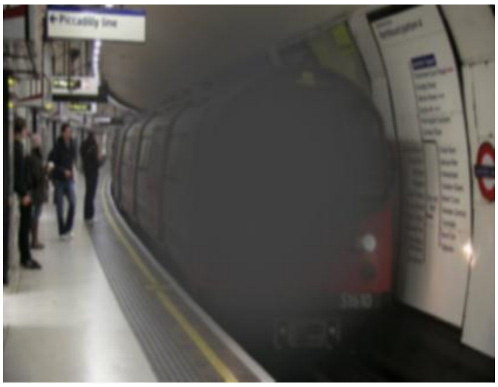

Figure 6. *Macular Degeneration.*

4.1.4 Pigmentosa. Pigmentosa is an inherited condition which causes severe tunnel vision. It is caused by an inflammation of the retina, and the symptoms can be present from birth. This impairment also causes a decrease in the ability to see in dark conditions, and it is possible for the central vision to also be affected. The preset for this impairment applies similar effects to the Glaucoma preset. The most apparent effect that is used for Retinopathy is the vignette effect, which is applied to recreate the tunnel vision symptom that is common with this impairment. A dark grey colour filter is also applied to the image to simulate the decreased vision in low light conditions. The final effect that this preset applies a moderate blur, which is used to replicate the general loss in the quality of vision, which is related to the inflamed retina (Figure 5).

4.1.5 Macular Degeneration. Macular Degeneration causes issues with the central vision of the eye such that the eye is unable to focus on anything and there is no sharpness or detail in the vision. This impairment is particularly common is older people, and is caused by a build-up of cell debris in the macular section of the retina, which in turn causes scarring and damage. The Macular Degeneration preset applies a special version of the 'Spots' effect to create an irregular, fuzzy, grey coloured circle at the centre of the input image. This is applied to simulate loss of central vision, and the diameter of the circle is increased relative to the severity of the preset. Also applied with this preset, is a blur effect which also increase with the severity, although to a lesser degree of intensity (Figure 6).

Figure 7. *Hyperopia preset.*

Figure 8. *Myopia preset*.

4.1.6 Hyperopia and Myopia. Hyperopia and Myopia are both classified as refractive errors of the eye. Hyperopia is commonly known as farsightedness, and Myopia is known as nearsightedness. Refractive errors are caused by a combination of factors relating to the size and shape of the various components that make up the eye. The size of the eyeball, deterioration of the lens shape, and alterations of the cornea, can all effect the way that the light that enters they eye can focus on the retina. If the light is incorrectly focused, objects closer or further from the eye appear to be blurry. The preset for Hyperopia (Figure 7) uses the radial blur effect to create an image where object closer to the viewer are out of focus, but ones further away are in focus. This is done by prompting the user to select the point in the image which is of the furthest distance. This is treated as the center point for the radial blur, and the radius of the focused area is adjusted based on the severity of the preset. For the Myopia preset (Figure 8), the same process is used, however the radial blur effect is inverted. This means that the most distant point selected in the image is blurred, and out of focus, and the areas that are closer to the viewer are in focus.

4.1.7 Colour Blindness. Colour blindness, also known as colour vision deficiency, is used to describe the different vision impairments that effect the way in which a person perceives colour. There are 8 different types of colourblindness presets that can be simulated by the system, these are: Protanopia (red blind); Protanomaly (red weak); Deuteranopia (green blind); Deuteranomaly (green weak); Tritanopia (blue blind); Tritanomally (blue weak); Achromatopsia (monochromacy); and Achromatomaly (blue cone). These are applied with the colourblindness effect, which works by multiplying the RGB pixels by manipulation values.

Figure 9. *Colour Blindness preset.*

Figure 10. *Edge detection tool.*

4.2 Tools

The analysis components of the app are used to demonstrate the comparisons between the original, unedited image and the newly created image, with the simulation effects applied to it. There are two tools that can be used for analysis: the canny edge detection tool and the side by side comparison tool. These provide the user with an easy way to contrast the differences between how their image appears through the eyes of impaired and unimpaired individuals.

4.2.1 Edge Detection. The edge detection tool highlights any perceived edges in the image as green lines. This can be used to contrast the difference that the visual impairment simulations have on the algorithms ability to detect edges, compared to the original. This feature is implemented using the JHLabs edge detection function which takes in a bitmap image as a parameter, and returns a new image containing the edge detection output. This function applies a 'Canny' edge detection algorithm to the image. The Canny edge detection works in multiple stages, and is fairly complex, however the overall process involves applying a Gaussian blur to the image, then observing the intensity gradients. After this, a non-maximum suppression is applied to reduce the likelihood of false detection, and then a double threshold is applied to examine possible edges. The final step is to suppress the discovered edges that are insignificant, and not connected to the larger edges.

4.2.2 Comparison. The second analysis feature is the comparison tool feature of the app. This provides a side by side comparison of the original image, and the image that has been distorted by the system. This tool places a slider on the screen which overlays the original image on the left side of the slider and the edited version of the image on the right side. The slider can be moved back and forth by the user to display different areas of both the edited, and original images.

4.2.3 Importing & Exporting. The tools section of the app focuses on the more basic aspects of functionality that are expected with any software package including saving and loading options. The user can choose to import an image from the devices file system, instead of capturing their own. The import image tool uses the standard Android 'Image Open Intent', which provides a premade activity that the app can switch to that allows the user to browse images easily. When the user selects an image file, the intent returns the user to the app with the image URI. This URI is then used to copy the image to the image variable used by the app to apply distortions to. Once the user has finished simulating visual impairments with the image, they have the option to export the output as an image file and save it to the device's local storage. Once saved, the images can be used in other applications, or included in documents, or printed. Saving is carried out using the Android 'File' object, which works similarly to the standard Java object. The image is saved to a folder within the file system that is created especially for the app which is created when the app is first executed.

Figure 11. *Comparison tool.*

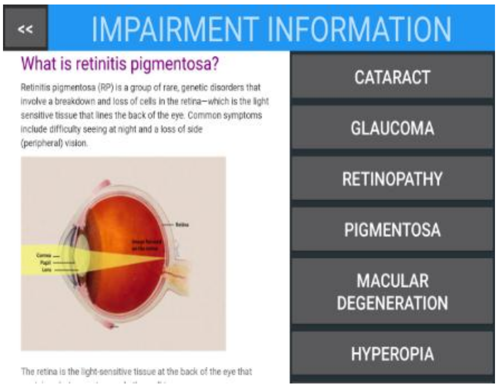

Figure 12. *Information tool.*

4.2.4 Image Capturing. While in the “image capture” mode, the app uses the screen to relay the input from the camera, which allows it to be used as a viewfinder. This feature is common among camera applications, and allows the user to capture images more easily. The capture button is placed on the left hand side of the screen, and is used to both capture images, and clear them. When an image has been captured, and the user wants to get rid of it to capture another, they press the capture button again. This deletes the image from memory, and returns the screen to the camera output for capturing.

4.2.5 Information. The app features an information section, which is accessed via the question mark button on the presets menu. This section is dedicated to providing information about the use of the app, and contains specific information about each of the individual impairments that are supported. This information is sourced from the National Eye Institute (NEI, 2016) website, and displays details about the relevant eye disease such as what causes it, and who it affects. This feature is implemented using the Android ‘WebView’ which is a view that displays web pages, and basically allows for a stripped down web browser to be added as a UI element within the app. The information section has a menu of buttons related to the visual impairments that are supported by the app. These buttons are linked to the WebView, and direct it to the relevant web page on the NEI website. This feature was added to allow the user to quickly and easily browse through relevant information about visual impairments without having to leave the app.

5. VALIDATION

The effectiveness of the app, its features and functionality and the accuracy of its simulations was undertaken through comparisons with previous work, a small focus group with potential student users, and an interview with a visual impairment expert. With regards to assessing accuracy of the simulated images there is no exact way of knowing whether the actual visual impairment representation is correct, a problem compounded by the visual impairments simulated by the app also have varying degrees of severity. The most plausible way of ensuring the validity of the simulation images, was thus to compare them to other simulations created during past research in this field (EDC, 2016), as well as to the symptom definitions created by official visual impairment organisations, such as the National Eye Institute (NEI, 2016) and the Royal National Institute of Blind People (RNIB, 2016). As part of this validation a full comparison of images was undertaken of the VISAD images and those produced by the Cambridge Inclusive Design Toolkit Simulator (EDC, 2016), one example of which is shown in Figure 15. From the images, little difference is evident between the two simulations, both involve rendering a large grey mass in the centre of the image, and include a slight blur to the rest of the image. The only slight difference between the two is that the simulation produced by the VISAD app applies slightly more blurred than the Inclusive Design Toolkit version, from this and the other comparisons we were able to conclude that VISAD simulations were accurate.

During the later stages of the implementation, the app was demonstrated to a focus group of 5 potential student users for testing and feedback purposes. This session involved providing the participants with ‘hands on’ experience with the app allowing them to test the various features of the app. Afterwards the group was interviewed about their impressions of the app, and what they liked and disliked about it. Overall feedback was very positive with all members of the focus group finding it interesting and easy to use once after minimal training on how to use the interface. Some minor errors in the UI were identified, further visual impairment presets were requested and the loading times for some of the more complex effects, such as the edge detection, was considered to be too long.

A meeting and demonstration of the app also took place with Dr. Geoffrey Cook, an expert in the field of accessible design and lighting in regards to the built environment. Overall he was very impressed by the app, and stated that ‘he knew of professionals that would be very interested in using the app’. He also expressed interest in the possibility of including further simulated effects of lighting in the app; and how different lighting levels would affect the images.

Figure 15. *Macular Degeneration comparison Cambridge (left) and VISAD (right).*

6. CONCLUSIONS

This project has created a visual impairment simulator, VISAD, (Visual Impairment Simulator for Auditing and Design) that runs on mobile devices and provides image capture, image processing and image export of visual impairment simulations. Allowing architects, designers, and accessibility auditors to visualize their projects from the perspectives of visually impaired people is essential in providing accessible and inclusive design. The overall benefits of utilizing a mobile platform for visual impairment simulation are that it makes the process more intuitive, more efficient, more educational and more impactful as immediate results can be seen. Using a mobile device allows simulations to be done in situ, with near instant results. This provides a much more fluid and convenient process compared with the previous desktop based systems, which lack integration of image capturing and processing aspects.

The comparison analysis that was carried out between the simulated images created by the app, and those created in earlier research projects and on visual impairment sites for professional organisations, show that the app can create very similar results. VISAD’s simulations for the visual impairment presets were of the same quality, or in some cases better than the ones used for comparison. Discussions with experts and potential users of the app have been highly positive and there is strong interest in using VISAD as part of the University of Reading’s Breaking down Barriers project which is embedding inclusive design into teaching and learning in built environment professional education and beyond and in inclusive design workshops run by the Department of Typography and Graphic Communication.

Due to the lower processing power of mobile devices compared to non-mobile devices, optimization is an area of consideration regarding further work on this project. Currently the system is limited to still images due to the processing time of the effects being too long for video, however, real time video processing is an additional feature that will be examined for the future.

An increased focus on the effects of lighting on visual impairments will also be included in future work resulting in increased complexity, sensitivity and accuracy of the ‘Light Source’ feature. There is also the potential to incorporate this project into a virtual/augmented reality simulation, which would allow the user to experience the impairments first hand in a more immersive environment. An IOS version of the app is also being considered.

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Differential effect of neutral and fear-stimulus virtual reality exposure on physiological indicators of anxiety in acrophobia

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ABSTRACT

This paper presents a study which explores the physiological and behavioural indicators of anxiety during exposure to a virtual reality environment. Using 10 participants (5 with acrophobia and 5 control) the study aimed to determine whether an increase in heart rate (HR) from baseline to VR exposure is a sufficient measure for effectiveness of a virtual reality exposure therapy (VRET) stimulus, or whether there is a mediating effect of neutral VR exposure which should be taken into account. The participants all explored an immersive cityscape at ground level and at height, and both subjective and objective measures of physiological arousal were recorded. It was found that the VRET was successful in inducing an anxiety response in the participants with acrophobia, and moreover demonstrated that an increase in HR from baseline to VRET on its own should not be considered a reliable indicator of VRET efficacy, but that there should be an adjustment for the effect of neutral VR exposure on physiological arousal.

1. INTRODUCTION

Irrational or excessive fear or anxiety is a common problem, with an estimated 40% of the general population suffering from one or more fears of a specific object or situation in the course of their lifetime, with around 10% developing a specific phobia (Van Houtem et al., 2013). Whilst some of these may be the direct result of a traumatic or harmful experience, many others are acquired through transmitted information or observation learning (Rachman, 1977). This can make them challenging to treat, as it is often not just a simple case of addressing the underlying causative incident, but modifying the underlying pathological fear structures (Edna B. Foa, Huppert, & Cahill, 2006).

One of the most common forms of treatment for this type of therapy is gradual controlled exposure to the feared stimulus ("exposure therapy"). Hofmann (2008) reports that exposure therapy involves a cognitive process of the extinction of fear by the absence of harm during exposure, and is at least as effective as the more complex cognitive therapy. Emotional processing theory (E. B. Foa & Kozak, 1986) suggests that exposure therapy may work by breaking the stimulus-fear-avoidance cycle, producing new networks by exposing the individual to the feared stimulus without harm. Indeed, even imagined exposure to the feared consequence strengthens the discrimination between "thoughts about harm" and "real harm" (Edna B. Foa et al., 2006). It is this ability of "imagined exposure" which is of particular interest, as it allows for the possibility of creating controlled virtual environment to support graded exposure.

This "virtual reality exposure therapy" (VRET) is being increasingly used to treat a variety of phobias and anxiety disorders (e.g. Carlin, Hoffman, & Weghorst, 1997; Emmelkamp et al., 2002; Mel Slater, Pertaub, Barker, & Clark, 2006), and has been demonstrated to be effective in reducing symptoms in vivo as well as in VR (Coelho, Waters, Hine, & Wallis, 2009; Parsons & Rizzo, 2008). However, the outcomes are not always consistent, and this may be due to a number of factors, including the individual patient (Krijn, Emmelkamp, Olafsson, & Biemond, 2004; Wiederhold & Wiederhold, 2000), the study protocol (Owens & Beidel, 2014; Parsons & Rizzo, 2008) or the virtual environment itself (Miyahira, Folen, Stetz, Rizzo, & Kawasaki, 2010; M. Slater, Pertaub, & Steed, 1999).

This paper is concerned with the last of these factors, the virtual environment, and the influence this may have on the efficacy of the VRET and hence on the treatment outcomes.

2. BACKGROUND

Exposure therapy is a neural reconditioning process, which presents the feared stimulus in the absence of harm, undermining the negative associations and creating a new cognitive network (E. B. Foa & Kozak, 1986). It is plausible that even exposure to virtual stimuli may support this cognitive reconditioning process, and indeed this hypothesis is supported by a number of reviews studying VRET outcomes (Coelho et al., 2009; Krijn et al., 2004; Parsons & Rizzo, 2008; Powers & Emmelkamp, 2008). However, studies vary in the reported efficacy of the VRET, and this may in part be due to the ability of the virtual environment (VE) to provide a suitable stimulus for effective exposure therapy.

Owens and Beidel suggest that effective VRET must meet three conditions in order to be consistent with the principles of emotional processing theory. Firstly, the exposure in the VE must be able to be generalised to real-life, secondly, the patient must feel present in the VR, and finally the VE should elicit physiological arousal (Owens & Beidel, 2014). To a certain extent, the first condition can be met by careful design of the VRET application. The second and third are closely associated, as a VE is unlikely to elicit physiological arousal without a sense of presence in the exposure to a virtual fear stimulus, and both behavioural observation and physiological measurement are considered valid measures of presence (Lee, 2004). Thus in order to evaluate the potential efficacy of a VRET application, we can use either behavioural observations or physiological indicators, as well as more traditional measures of presence.

Previous studies have shown that VRET can elicit physiological arousal (Owens & Beidel, 2014; Mel Slater et al., 2006), but this has not generally been correlated to observable behaviour changes or subjective distress. For example, a study which compared reported presence to physiological observations used only a general presence questionnaire, and did not include any behavioural observations (Meehan, Insko, Whitton, & Frederick P. Brooks, 2002). When evaluating such studies, it is difficult to be certain whether the increased physiological arousal can be attributed to a fear stimulus, or to some other factor of the virtual environment. In addition, it is not certain whether exposure to virtual reality can itself trigger physiological arousal, even in the absence of fear or distress.

Slater et al., (2006) demonstrated a significant difference in heart rate (HR) between speaking in an empty virtual room and speaking to a virtual audience, confirming that HR within a virtual environment is dependent on the level of stimulus. However, in the absence of baseline (non-VR) HR data, the level of elevation of HR which would indicate successful fear-arousal is unclear. It has been suggested that an increase in HR >15 bpm is indicative of sufficient immersion for exposure therapy (Walshe, Lewis, Kim, O'Sullivan, & Wiederhold, 2003), but again this study did not examine the change in HR from non-VR to baseline VR, and so could not differentiate between rise in HR due to the fear-inducing stimulus from that induced solely by exposure to VR.

We suggest that in order to evaluate whether a virtual environment meets the conditions necessary for VRET, it is necessary to demonstrate that the fear stimulus has a differential effect on physiological arousal beyond that which may be induced by baseline VR exposure. In this preliminary study we expose both an acrophobic group and a control group to an immersive VR environment followed by a virtual height stimulus. We hypothesise that there will be an increase in HR on exposure to VR, even in the absence of a fear stimulus, and that there will be a further increase in HR when participants are exposed to the virtual height. Further, we hypothesise that there will be a differential change in HR between phobic and non-phobic participants when exposed to height, but not in the other conditions. Finally, we hypothesise that there will be correlations between observed behaviour, reported anxiety and HR in the VR exposure.

3. METHOD

The study was a mixed 3x2 factorial design, with one within-subjects factor (VR condition), and one between-subjects factor (acrophobia).

The VR exposure and the acrophobia tendency were the independent variables, and heart rate (HR) was the primary dependent variable. In addition, presence, subjective fear and behavioural observations were recorded.

3.1 Participants

Ten participants were recruited from the School of Creative Technologies. There were 8 males and 2 females, aged from 19-26 (mean age 22). Five participants reported mild or moderate acrophobia, and five reported no fear of heights.

Table 1. *Participant demographics.*

Participant	01	02	03	04	05	06	07	08	09	10
Acrophobia	None	None	Mild	Mild	Mild	None	None	Moderate	Moderate	None
Age	21	22	24	20	26	19	21	21	21	21
Gender	m	m	m	m	m	m	m	f	f	m

3.2 Measures

On arrival, participants were asked for a self-rating of their fear of heights. This was coded as none=0, mild=1 and moderate=2. Heart rate data was recorded continuously via a Polar H7 monitor during the pre-exposure, VR-neutral exposure and VR-height phases of the study.

Behavioural observations were made throughout the interaction with the virtual environment. Behaviours were coded from 0 (no signs of anxiety) to 5 (signs of severe anxiety).

A post-test short questionnaire (M. Slater & Usoh, 1993) evaluated the sense of presence during the VR exposure, and participants were also asked to rate their subjective sense of fear during the exposure on a scale of 1-10.

3.3 Experimental setup

As previously discussed, it is important to induce a sense of presence ("being there") for effective VRET. In order to evaluate the differential effect of VR stimuli on HR, we need to use a virtual environment which is optimised to support the induction of presence. Since the visual quality of the environment and the level of interaction available to the user are both important factors in inducing a sense of presence (North & North, 2016), we designed a realistic virtual cityscape and used full body motion capture to support fully immersive interaction.

For the virtual environment to run smoothly during the VR exposure several optimisations had to be made, one of which was combination of low and high polygon 3D assets to ensure that frame rates do not drop below comfort zone of around 75fps. A technique known as *Level of Details* (LODs) was used to dynamically adjust the detail of meshes in the virtual environment depending how close the participant is to the object. The further away the object, the lower the detail it will have and closer you get towards it the sharper the textures and more polygons will be visible resulting in greater overall performance and more pleasant experience.

A 3D model of a cityscape was created in Autodesk 3DS Max and then deployed in Unreal Engine 4. Physical based rendering (PBR) was used in order to create realistic lighting effects. A walkway between two buildings was constructed on the 5th floor, and this was made of a combination of concrete and glass textures. Finally, there was a lookout point on the roof of a seven-story building (Figure 1).

Figure 1. *From left to right: Cityscape, concrete and glass walkway and roof lookout point.*

The participants' motion was captured using Vicon T10 cameras and a full-body motion capture suit with 59 markers. A PC was used which was capable of running the motion capture and application in real time at a minimum frame rate of 120fps. Between the Motion Capture hardware and Unreal Engine 4 it was essential to have a solution which streamed the data captured from the body motion, and translate it to a rigged animation in real time. For this we used Vicon's Pegasus retargeting software. This allows us to bridge both technologies seamlessly and result in highly responsive real-time full body control in the virtual environment.

Participants viewed the virtual environment using the Oculus Rift DK2, and their movements were mapped directly onto a self-avatar, with real-time rendering of shadows.

3.4 Procedure

Participants were briefed on the study and signed an informed consent sheet. They were also reminded that they could stop the study at any point if they felt uncomfortable or overly anxious. They were then fitted with the Polar H7 monitor on a chest strap, and then donned a motion capture suit. Fifty-nine optical markers were applied at predefined anatomical landmarks (Figure 2), and a calibration sequence of movements was performed. During this time (3-5 minutes) a baseline HR was recorded.

Figure 1. *The motion capture suit with optical markers.*

The participants were then fitted with the head mounted display and were able explore the cityscape at ground level. They were given a few minutes to acclimatise to the VR environment and the VR-baseline heart rate was recorded during this time.

Finally, the participants were asked to close their eyes for 10 seconds while they were moved to the elevated areas of the virtual environment. They were given a number of tasks, including stepping onto the bridge, crossing over a glass area, and leaning over the rooftop to look down to the street, which accumulated around 10 to 15 minutes for each participant's total exposure. Again, HR was recorded during this VR-height exposure.

After the completion of the tasks at height (or sooner if the participants requested "escape" from the scenario), the participant completed a questionnaire with 3 questions to score the sense of presence, a Likert score for the level of fear experienced, and a free-text question regarding aspects of the experience which interfered with the sense of presence.

4. RESULTS

4.1 Effect of VR condition on Heart rate

A repeated measures ANOVA was conducted to compare the effect of no-VR, VR, and VR-height exposure on heart rate (HR). There was a significant effect of VR condition on the mean HR [$F(2,18) = 87.54$, $p = .000$.].

Post hoc comparison demonstrated that HR was significantly lower in no-VR than VR [$t(9)=10.57$, $p=0.00$.], lower in no-VR than VR-height [$t(9)=5.51$, $p=0.00$.], and lower in VR than VR-height [$t(9)=8.19$, $p=0.00$.] (Figure 3).

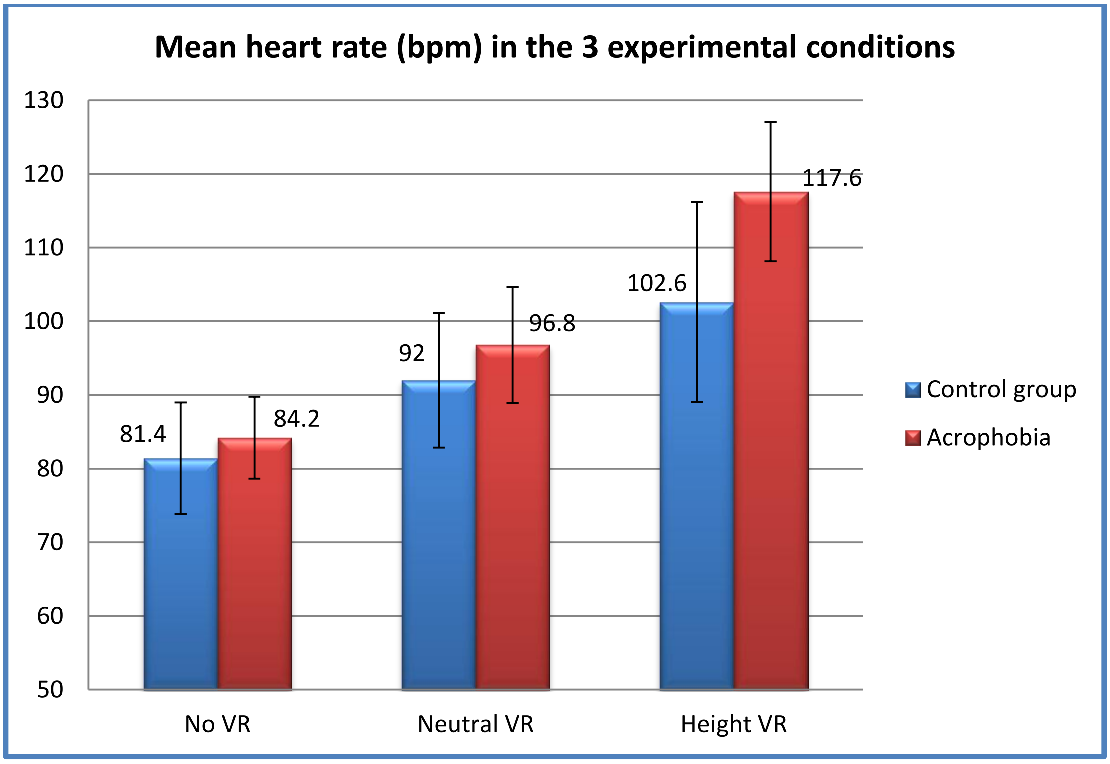

Figure 3. *The differential effect of non-VR, neutral VR and VR-height on heart rate.*

4.2 Differential effect of acrophobia on HR during fear stimulus

There was a positive correlation between the level of acrophobia and the VR-height HR [$r = 0.679$, $n = 10$, $p < 0.05$]. There was no correlation between the level of acrophobia and the baseline HR or neutral-VR HR.

4.3 Correlation between behaviour, HR and reported anxiety during fear stimulus

There was no anxious behaviour observed while the participants explored the city street, and all the observed anxious behaviour occurred during exposure to the height stimuli. There was a positive correlation between the observed anxious behaviour and the reported level of fear [$r = .909$, $n = 10$, $p = 0.00$.], between the observed behaviour and the HR at height [$r = .655$, $n = 10$, $p < 0.05$], and between the reported level of fear and the HR at height [$r = .827$, $n = 10$, $p < 0.01$].

5. DISCUSSION

This study set out to explore the differential effect of neutral and fear-stimulus VR exposure on physiological indicators of anxiety. There was a significant increase in HR on exposure to neutral VR environments in both groups, with a mean rise of 12 bpm. This rise was not associated with any anxiety behaviour, and was not correlated to the level of acrophobia. Since the suggested indicator for successful immersion for exposure therapy is only 15 bpm (Walshe et al., 2003), it would appear that we run the risk of a false positive evaluation of a VRET if we compare non-VR HR to exposure HR without adjusting for the direct effect of neutral VR exposure on HR.

The exposure to the VR height stimulus elicited a further significant rise in HR in all groups, but this time there was a significant correlation between reported acrophobia and the increased HR, with the mean increase in acrophobia being 19.4 bpm, compared to a rise of 10.6 bpm in the control group. Furthermore, all of the acrophobia group experienced a minimum rise of 15 bpm when moving from the neutral VR stimulus to the VR height stimulus. This suggests that the 15 bpm could indeed be a useful indicator of a successful exposure in a VRET environment *but only when it has been measured from a neutral VR* baseline. Indeed, when the increase in HR is compared directly to baseline, without adjusting for VR exposure, 80% of the control group (no acrophobia) exhibit a rise >15 bpm, without showing any sign of anxiety behaviour or reported fear.

This study is not without its limitations. The initial sample size is small, and does not have an equal gender balance between groups, additionally all participants do come from the School of Creative Technologies which is a clear limitation. Although this may not have influenced the results, a larger sample with a more homogenous demographic distribution is needed to confirm these initial findings. Furthermore, activity is known to influence HR, and although the participants were able to move around in all three conditions, it was not possible to completely control for any potential effect of movement on HR. A follow-up study with seated participants would help to identify any movement-artefacts in the recorded HR data. Finally, there were a number of incidents which caused a break in immersion, including "stepping off the edge", hearing other voices in the motion capture room, and "retargeting errors" on the hands of the avatar. For a future study, the participants would be issued with noise-cancelling headphones, and a more robust smoothing algorithm used to maintain consistent movement of the avatar. Whilst there is a good correlation between observed behaviour scores and the respective self reporting of anxiety and the recorded heart rate, the behaviour coding was not a standardised coding system but was created bespoke for the project. The observational data was recorded by the author without prior knowledge of the behaviour coding. The coding of behaviour was then designed by a second member of the team and then applied to the observational data. This was then checked and found to be relatively consistent in its application and interpretation across the participants by a third member of the team. Such an approach, whilst mitigating bias, does have limitations and in future work a blind double coding approach will be applied from the outset. It has been suggested that passive haptics can significantly increase presence in VR (Meehan et al., 2002), and thus the use of a raised surface for the bridge, and a small platform for the roof would be used in future studies

In summary, this study is the first to indicate the need to adjust for the rise in HR in neutral VR before using HR increases as an indicator for successful VRET fear stimulus. It is important to elicit the physiological and behavioural responses of anxiety during exposure therapy in order to achieve successful extinction of fear during the therapeutic process (Owens & Beidel, 2014), and careful evaluation of the VRET stimulus environment before deployment should facilitate more consistent outcomes.

Acknowledgements: With thanks to Alex, Joe and Scott for assisting with the motion capture and supporting the data collection for the study.

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Bringing the client and therapist together in virtual reality telepresence exposure therapy

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ABSTRACT

We present a technology demonstrator of the potential utility of our telepresence approach to supporting tele-therapy, in which client and remote therapist are immersed together. The aim is to demonstrate an approach in which a wide range of non-verbal communication between client and therapist can be contextualised within a shared simulation, even when the therapist is in the clinic and the client at home. The ultimate goal of the approach is to help the therapist to encourage the client to face a simulated threat while keeping them grounded in the safety of the present. The approach is to allow them to use non-verbal communication grounded in both the experience of the exposure and the current surroundings. While this is not new to exposure therapy, the challenges are: 1) to do this not only when the threat is simulated; and 2) when the client and therapist are apart. The technology approach combines immersive collaborative visualisation with free viewpoint 3D video based telepresence. The potential impact is to reduce dropout rate of exposure therapy for resistant clients.

1. INTRODUCTION

Exposure therapy is an effective treatment for phobias and post-traumatic stress disorder (PTSD). Yet it suffers high dropout rates, especially in resistant populations. Drop out can come from lack of engagement, symptoms heightening at outset of therapy, or reluctance of clients to travel to the clinic. Virtual Reality Exposure Therapy (VRET) offers potential to address the first two, and its derivative tele-VRET, the latter. We argue that the typical approach of using Head Mounted Displays (HMD) in VRET and desktop displays in tele-VRET focusses attention on threat and blocks or hinders non-verbal communication (NVC).

We present a demonstrator of a new approach to tele-VRET that addresses this. Within this the therapist and client share a virtual space with the simulated threat in such a way likely to both support a wide range of contextualised NVC and promote a feeling of togetherness. In this, the client faces a life sized 3D video of the therapist moving within a virtual environment that contains emotive stimuli. In the current demonstrator the client is captured through 2D video to allow for easy deployment in the home. Both can judge where the other is looking. The therapist can move between the client and the emotive stimuli or stand to one side and gesture toward or away from it, in this way managing their attention. Our approach allows the therapist to determine if the client is looking at them, fixating on or away from the simulated threat, or following instructions to look toward the real world. A limitation of the current demonstrator is that while the therapist can move freely, gaze estimation will be effected if the client moves off the central line of their camera. A symmetrical system that captured 3D video at each side would allow both to move in any direction without fragmenting spatial context. We also demonstrate how video based reconstruction can be used to rapidly create 3D recordings of actors approaching levels of realism that traditionally take much longer capture and rework.

2. RELATED WORK

VRET has been studied across an extensive range of phobias but perhaps most deeply with Post-Traumatic Stress Disorder (PTSD). Within PTSD, VRET has demonstrated potential efficacy and appears to be more engaging to resistant groups (Gonçalves et al., 2012). Yet drop-out rates, at approaching 40%, remain similar to non-technology based exposure therapy (Gonçalves et al., 2012).

Awareness of both memories and current present-moment experience is seen to facilitate exposure in traumatised individuals (Rothschild, 2003). Conversely, “immersive virtual environments can break the deep everyday connection between where our senses tell us that we are and where we actually are located and whom we are with” (Sanchez-Vives and Slater, 2005). Rothschild explains how the therapist uses non-verbal communication to detect fixation and bring attention back to the present. Yet VRET typically uses Head HMDs (Gonçalves et al., 2012) that completely block both the present surroundings and therapist from view.

Tele-VRET has been demonstrated but uses desktop interfaces through which avatars representing client and therapist come together in a world, all shrunken to fit within a small monitor. Such systems support little non-verbal communication or feeling of togetherness (Roberts et al., 2015a). People seem to react to life-sized virtual humans as if real, following natural patterns that relate gaze and interpersonal distance (Bailenson et al., 2001). Subtle changes in gaze and posture of virtual humans alters people's comfort (Pertaub et al., 2002). People respond naturally to virtual avatars in distributed immersive collaborative environments (Steed et al., 2005). We have extended such systems to support mutual eye-gaze (Roberts et al., 2009). However, these avatars still do not look like the person whose movements they copy and do not reproduce faithful facial expressions. We have thus developed 3D video telepresence to communicate both what someone looks like and what they are looking at (Roberts et al., 2015a). This technology produces live 3D graphical copies of people, and any items around them, into another space.

Others combined video based reconstruction with an immersive display (Gross et al., 2003) demonstrating how spatial and visual qualities could be better balanced. However, visual and temporal qualities were still some way behind what could be achieved with motion tracked avatars. Since then, visual qualities of video based reconstruction have significantly improved (Grau et al., 2007), (Waizenegger et al., 2011). Recent (Divorra et al., 2010) and current (Steed et al., 2012), (Garcia et al., 2015) funded EU research focuses on spatial telepresence. The potential utility of our approach in collaborative work has been demonstrated within the realm of space science and exploration (Garcia et al., 2015, Roberts et al., 2015b). This technology could be used to join clinic and home.

3. OUR TELEPRESENCE SYSTEM

The ultimate aim of our telepresence system is to situate people from different physical locations into a shared simulated context within which they communicate through a wide range of non-verbal resources. Unlike 2D video based approaches, each can see where the other is looking as they move. This system has been described before (Roberts 2013). Here we summarise what it tries to solve, its approach and current state.

Unlike spoken word, NVC and its use in social interaction is inherently spatial. Just as words link together to provide meaning, so do various non-verbal signals, along with their context. In the natural world, gaze, interpersonal distance and other non-verbal cues of familiarity are linked and used to allow people to manage relationships with each other. Even board room meetings typically start and end with people going up to each other, making eye contact, smiling and sometimes tapping a shoulder or shaking hands. It is these things that grow the trust between people needed for an effective meeting.

Video conferencing supports some of NVC useful in promoting trust and togetherness. Such technology ranges from Skype on a phone to carefully aligned screens and cameras around a table. 2D Video however, loses much of the spatial grounding for NVC. Spatial context can only be accurately determined within the space of the observed, rather than across the spaces of the interactants. While cameras and screens can be aligned to support some approximation of gaze interaction, this only begins to work when people remain in the centre line of the camera. Problems of aligning camera and image of face and the Mona Lisa effect greatly limit this approach and restrict support for relationships between gaze and interpersonal distance. Video conferencing can be said to faithfully communicate visual but not spatial qualities of non-verbal behaviour.

Immersive Collaborative Virtual Environments (ICVE) offer the other extreme, where non-verbal communication between interactants can be situated in a shared virtual context but at the expense of visual faithfulness and many subtleties, such as facial expression. In such a system, people in different displays can move around a shared context together, seeing each other as life sized CGI avatars. We have previously extended ICVE with eye gaze (Roberts VR'09). Such a system theoretically supports the relationship between personal space and eye gaze although this has not been tested with rigour. ICVEs can be said to faithfully communicate spatial but not visual aspects of non-verbal behaviour.

Numerous video based approaches to reconstructing humans have been applied to telepresence. In theory, these should be able to faithfully communicate both visual and spatial qualities of non-verbal communication. However, balancing the two, especially with temporal qualities remains challenging (Roberts, 2013). This is the challenge that our telepresence system is set against. Specifically we want to faithfully communicate both visual and spatial aspects of non-verbal communication to within the limits of their use in non-touch interaction. This means being able to, for example, look someone in the eye and see if they smile as you enter their personal space, perhaps from the side.

Figure 1. *3D reconstruction of a human in our telepresence system, showing lines from each camera derived from silhouettes.*

Our approach combines real time free viewpoint video with large projection displays. An end to end description of the system is given in (Roberts et al., 2015a). It adopts the video based construction approach of visual hull, using our parallel adaptation (Duckworth and Roberts, 2014) of the EPVH algorithm (Franco and Boyer, 2003). Users stand within an immersive display system and are captured by surrounding cameras, figure 1. Silhouettes from the images are then used to shape carve a form, onto which the original images are textured. This live textured model can then be sent to another immersive display system to be placed within the spatial context of a shared simulation and another user.

We have built many prototype versions that between them demonstrate that all the fundamental requirements are achievable with our approach. However, we have not yet built a single version that fully meets all. At this point in time, we are able to build demonstrators of principle and undertake perceptual experimentation such as (Roberts et al., 2013). However, we have yet to build complete an end-to-end symmetrical system that would demonstrate a sufficient balance of visual, spatial and temporal interaction to support meaningful behavioural experimentation. This paper presents a novel demonstrator.

4. DEMONSTRATION OF THIS SYSTEM APPLIED TO VIRTUAL REALITY TELEPRESENCE EXPOSURE THERAPY

We now describe: the problem we are trying to solve, our general approach, an example scenario, the technology set up, and the limitations.

The problem that we are trying to solve is managing the emotional distance to threat while: 1) the threat is simulated; 2) the client and therapist are in different buildings. The approach we are taking is inspired by Rothschild (Rothschild, 2003) who attempts to mediate a client's awareness of threat and safety of the present, making use of verbal and non-verbal communication.

Our approach is to share a virtual context through large displays while using video based reconstruction to recreate both the therapist and, in this case, the threat. In another case the threat might be completely virtual. The concept is that the therapist can interpret both attention and emotion of the client through non-verbal signals and use non-verbal communication to direct the client's attention and, by doing so, manage emotion their emotion.

In this scenario, the shared virtual environment represents a non-threatening place. The therapy scenario is one of social anxiety. The people in Figures 2 and 3 are authors playing out parts. The three parts being played are: therapist, client and threatening other. In Figure 1 the "client" looks straight at a threat that has just approach through a door. In Figure 3, the "therapist" steps between them and uses gesture and gaze to direct the client's attention to a neutral object, the sofa.

To demonstrate this principle and primary issues we have created an asymmetric system by linking two large displays with two different kinds of mediums (Figure 4 & 5). Asymmetric telepresence systems have been used to demonstrate the impact of differences in VR technology on collaboration (Slater et al., 2000) (Roberts et al., 2003). Our demonstration does not attempt to address every issue but does attempt to demonstrate the key issues and the fundamental qualities of our approach towards addressing them. The client side uses very simple technology that would be relatively straight forward and inexpensive to replicate in the home. The key components are a large flat screen onto which the shared virtual context is displayed and a camera. The therapist side is more complicated but could still be replicated within a clinic without excessive disruption or expense.

Figure 2. *The client in the foreground is approached by a threatening other. The threat is a pre-recorded 3D reconstruction of someone approaching aggressively.*

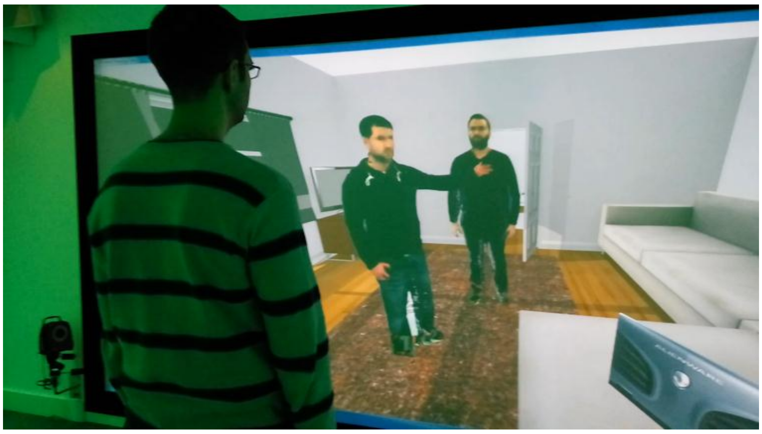

Figure 3. *A mock up of a client fixating on a virtual threat and the therapist stepping in front of it. The therapist (centre) is reconstructed in real time across the telepresence link.*

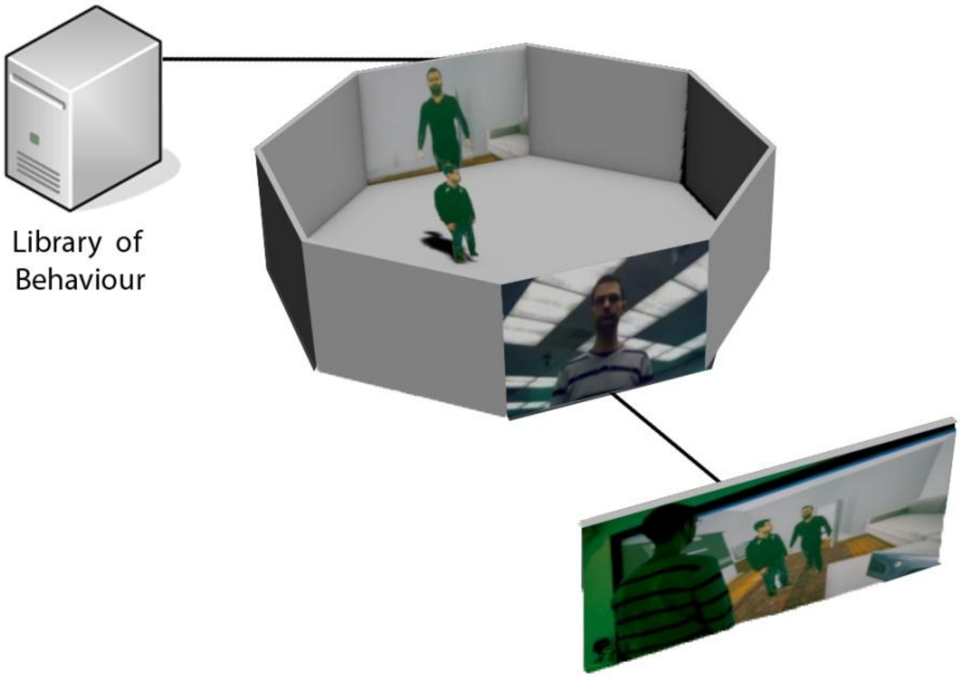

Figure 4. *Diagram of the asymmetric telepresence system built for this demonstrator.*

The two fundamental differences are the use of two screens and a ring of cameras. The face on view of the "client" is transmitted via skype to a display wall in front of the "therapist". The rear portion of the partially shared virtual environment is displayed behind the therapist. A ring of cameras looks down at the therapist from above the screens. Each is angled so that while capturing the therapist moving within a portion of the space, neither screen is seen. This allows us to use a simpler and faster method of background segmentation that does not need to account for moving images. Between these two displays, the therapist can look ahead to see the client and behind to see the back of the virtual room the client looks into. The "therapist" appears in the foreground of the partially shared virtual space, as seen by the "client".

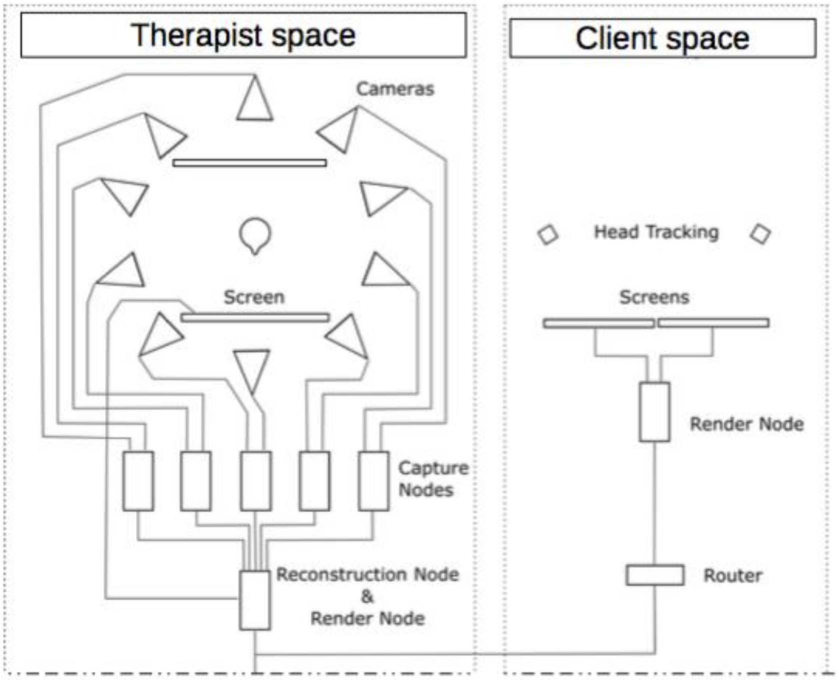

Figure 5. *System Architecture of this demonstrator.*

5. DISCUSSION

An ideal VRET and teleVRET system would allow client and therapist to be immersed together within the simulation without restricting NVC and its contextualisation in any way. Currently this could nearly be supported for co-located VRET using large immersive display systems. All apart from one potentially significant problem, the need to ware 3D glasses that hide the eyes. TeleVRET is more challenging, not least as it requires easily deployable, unobtrusive, easily maintained, low cost solutions for the home end. We have presented a pragmatic approach to this that uses today's technologies in a novel way. It may be many years before technology is available that allows people in different places to seamlessly share each other's spaces. At present we must make a compromise between freedom of movement across the shared simulation against complexity of system and the issues of each complexity.

The demonstrator we have presented is meant to convey concept, pragmatic approach and issues rather than an ultimate system. It demonstrates a range of technologies put together in a pragmatic way. Both simpler and more advanced approaches could be derived from this. The most advanced would allow a full sharing of virtual context in which client and therapist could move around together. The current and simpler versions provide a partial sharing of context which imposes restrictions on movement within the shared space. However, the demonstrated and simpler approaches are far more deployable, affordable and maintainable given current technology. Our approach could be described as partial as it does not allow both parties to move across the full extent of the shared space. However, we felt it was more important to show a practical solution achievable today within people's homes. Until fully immersive stereo can be achieved without stereo, there has to be a compromise between freedom of movement across shared space and ability to determine eye gaze. We were able to support a "therapist" judging the gaze of a "client" and moving between the client and the "simulated threat" he gazed at, and gesturing to a less threatening part of the simulation.

This is not the first time that immersive projection technology has been used in VRET. However, we are unaware of a publication describing its use to support non-verbal togetherness of client and therapist or communication between them. This is not the first time that immersion and life sized avatars have been used to improve feelings of togetherness or contextualise non-verbal communication. For example, we have previously described our technology approach to faithfully communicating both appearance and attention by combining immersive displays with free viewpoint 3D video based avatars. We have also previously described its application to collaborative working. This is the first time its potential application to exposure therapy has been described.

6. CONCLUSION

The primary contribution of this paper is demonstrating how to support the kind of non-verbal communication used between client and therapist in exposure therapy, firstly when the stimuli, and secondly the other, appear through technology. The methodological contribution is using video based reconstruction in tele-therapy for the first time.

We have demonstrated how video-based reconstruction could potentially be used in virtual reality telepresence exposure therapy. This potential utility is in three parts:

- Making the client feel less alone within a threatening simulation. This is because it supports the range of non-verbal resources used to manage social distance and build feelings of trust and rapport.
- Helping the therapist to manage the client's anxiety and attention. Contextualisation of non-verbal communication is necessary for both.
- Potential utility in creation of visually realistic virtual humans, rapid enough to fit within a course of therapy. Conventional approaches take weeks of authoring.

We have sort to demonstrate concept, pragmatic approach and issues:

- The concept is that the therapist and client can be situated together within the simulation, to allow most of the range of non-verbal communication used by many therapists to manage a client's distance to threat.
- The approach is to combine 3D free-viewpoint video based reconstruction with large display systems and simulated environments.
- The issues are around compromise between complexity and deployability of the system.

Rather than demonstrating an approach that maximises the level of sharing of the simulation, we have demonstrated an asymmetric and pragmatic approach that is less complex, cheaper, more deployable and likely to better retain grounding in the real world. This asymmetry also allows us to demonstrate the impact of technology choices.

The potential impact of this approach is in reducing dropout rates of exposure therapy. This is important as dropout rates of 40% are not uncommon in resistant populations. Furthermore, as symptoms typically increase at the beginning of a course of exposure therapy, clients can dropout with negative health impacts. We argue that by allowing clients to both use virtual reality exposure therapy and work with a therapist at home, reduces the risk of non-attendance to therapy sessions. This could impact not only on success rate of treatment but in reducing costs to health providers through reducing missed appointments. We further argue that allowing the therapist and client to see each other and estimate what the other is looking at, would help to manage the grounding of the client in the safety of the present. This again has potential to reduce dropout rates by reducing the risk of retraumatisation and improving the relationship between client and therapist. While remote therapy can be done with conventional video conferencing and CGI avatars, the levels of non-verbal communication used within a clinical therapy session are not supported. Our approach has the fundamental properties to support them much better. Our demonstrator shows both the issues and the principles of the solution.

Acknowledgements: The authors with to thank Charlie Moritz from Freedom form Torture, Allan Barret from Pennine NHS Care Trust, Warren Mansell from University of Manchester and Linda Durbrow-Marshal from University of Salford for helping us understand the relationship and interaction between client and therapist and what needs to change in VRET to accommodate this. We also wish to thank the technology team at Salford that have helped in the past to develop the telepresence system, including Toby Duckworth, Carl Moore and Rob Aspin and John O'hare.

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Experimental pain reduction in two different virtual reality environments: a crossover study in healthy subjects

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ABSTRACT

The literature on unique virtual reality (VR) attributes impacting pain reduction is scarce. This study investigated the effect of two VR environments, with differing cognitive load (CL) demands, on experimental pain levels. Sixty-two students underwent psychophysical thermal pain tests, followed by exposure to tonic heat stimulation under one of three conditions: low CLVR (LCL), high CLVR (HCL), and a control. Significantly greater pain reduction occurred during VR compared to the control condition. Cognitive components predicted pain reduction during HCL only. Cognitive load involved in VR may influence the extent of pain decrease, a finding that may improve treatment protocols and promote future research.

1. INTRODUCTION

Distraction is a process in which attention is directed away from the nociceptive stimuli and results in change in the quality and quantity of pain (Van Damme, et al., 2010). Distraction can be achieved when attention is directed towards another sensory modality such as visual, auditory or tactile stimuli (Miron, et al., 1989), and is commonly evoked by various cognitive tasks (Eccleston & Crombez, 1999). Several former studies have suggested that the cognitive load involved in the task impacts the level of pain decrease (Miron et al., 1989).

Virtual reality (VR) is an advanced and useful technology that can be used for distraction from pain (Mahrer & Gold, 2009). Most of the previous studies examining the effect of VR on pain included burn pain patients, demonstrating the effectiveness of the technique in relieving pain during wound care (Hoffman et al., 2004; 2008) and physical therapy (Carrougher et al., 2009). In the laboratory setting, there is also evidence showing the efficacy of VR in reducing experimental evoked pain in healthy subjects; such studies were conducted using diverse methodologies regarding both pain measures and VR paradigms (i.e. Hoffman et al., 2003). However, there is scarce literature examining the specific attribute of VR in reducing pain or relating to the cognitive effort that individuals need to invest in the environment in order to perform the task correctly, a key for implementing the approach as part of individualized medicine.

Therefore, the aims of the present study were to: (1) investigate the effect of participation in two VR environments, which differed in terms of cognitive load (CL) demand on experimental evoked pain scores, in healthy subjects; (2) identify predictive factors affecting pain reduction during participation in VR.

2. MATERIALS AND METHODS

2.1 Subjects

Sixty-two healthy subjects (31 males, 31 females, mean age= 24.2 SD=3.7 years), with an age range of 18–35 years, who were Hebrew speakers, free from any type of pain, not taking any medication, and able to communicate and understand the purposes and instructions of the study.

2.2 Experimental Pain Models

Cold Pressor Test (CPT) – cold pain threshold, tolerance and intensity. The CPT apparatus (Heto CBN 8-30 Lab equipment, Allerod, Denmark) is a temperature-controlled water bath with a maximum temperature variance of ±0.5 C, which is continuously stirred by a pump. Subjects were instructed to place their right hand in the CPT in a still position. A stopwatch was simultaneously activated, and subjects were requested to keep their hands submerged in the cold water for as long as possible. A cut-off time of 180 seconds was set for safety reasons. Subjects were instructed to indicate the exact point in time when the cold sensation began to elicit pain. The time until the pain was first perceived was defined as time to pain onset (seconds). In the current study, the water temperature of the CPT was 5ºC. Immediately after hand withdrawal, subjects were asked to mark their maximal pain intensity on a 0–100 numerical pain scale (NPS), where 0 represented "no pain" and 100 represented "the worst pain one could imagine." The latency of intolerability (spontaneous hand removal) was defined as pain tolerance (seconds). Tolerance for subjects who did not withdraw their hand for the entire 180 seconds was recorded as 180 seconds.

Thermal Sensory Analyzer (TSA) – thermal thresholds and pain intensity. Cold and heat pain thresholds were determined with the method of limits on a Medoc TSA-2001 device (Medoc, Israel). A Peltier thermode (30 x 30 mm) was attached to the skin above the thenar eminence. The baseline temperature was set at 32.0°C and was increased or decreased at a rate of 1°C/s. The stimulator temperature range was 0–50°C. Subjects were instructed to press a switch when the stimulus was first perceived as painful heat or cold. Three readings were obtained for each thermal modality (cold and hot), and their averages were determined as pain threshold scores. The TSA was also used to determine sensitivity to noxious heat stimulation. Subjects were exposed to tonic heat stimulation (46.5ºC, for 120 seconds) on the medial part of their left ankle and asked to report the perceived pain intensity (NPS 0–100).

Assessment of CPM. Conditioned pain modulation (CPM) is considered to be a manifestation of pain inhibition. CPM describes a state whereby the response to a given noxious test stimulus is attenuated by another conditioning stimulus that is simultaneously administered to a remote area of the body (Yarnitsky et al., 2010). In order to induce a CPM effect, phasic heat stimulations were given and considered the "test stimulation," whereas cold stimulation was used as a "conditioning" stimulation. For further elaboration see Demeter et al. (2014).

2.3 *EyeToy*

The current study included two EyeToy (Sveistrup et al., 2003) environments: both environments were taken from "EyeToy Kinetic" (EyeToy games CD). The environments were chosen because of their similar motor requirements. In the first environment, named "Backlash," the subject is required to move his upper limbs and right leg, to avoid contact with four paddles, two paddles on each side of the screen, with a central circle. In the second environment, named "Equilibrium," the subject is required to move his upper limbs and right leg and be precise in touching light beams appearing on the screen in different positions.

2.4 *Self-Feedback VR Inventory*

For the purpose of the current study, four questions were chosen from the Presence questionnaire (Witmer & Singer, 1998). The questions were chosen based on an analysis conducted by the researchers comparing the differences between the two VR environments, as well as the activity analysis results. The inventory includes a Likert scale of 1–5 (1=not at all, 5=a lot) which evaluates: 1. the ability to predict what will happen in response to the subject's action (anticipation); 2. the feeling of skilled movement and interaction with the VR environment (movement skills); 3. the ability to block external distraction and concentrate on a task (attention and cognitive inhibition); 4. the extent of physical effort demand during task (physical effort).

2.5 *Activity Analysis Form*

In order to thoroughly analyze and identify different aspects of each VR environment, "expert validity" was conducted with four experts, using an activity analysis form (Murphy & Davidshofer, 1994). This qualitative-based form includes 73 items reviewing general aspects of the activity (16 items, such as: activity description, required preparations or activity structure) and activity performance components: motor (16 items), sensory (16 items), cognitive (14 items), psychological (19 items) and neuromuscular (8 items). The experts rated each item, answering whether the specific attribute is manifested in each of the VR environments. In addition, they provided a qualitative evaluation regarding the VR environments s/he was exposed to (Drake, 1991).

2.6 *Study Procedure*

Determining VR Environment Characteristics. Four experienced Occupational therapists actively participated in each VR environment and completed the activity analysis form immediately afterwards. Intraclass correlations (ICC) as estimates of interrater reliability were calculated using SPSS software version 19. The results showed that in the LCLVR, ICC= .92 $p<.000$, and in the HCLVR, ICC= .95 $p<.000$. Meaning that, there was a high level of agreement between raters regarding the activity analysis of both VR environments. According to the experts' evaluation, the main characteristics of each environment were identified and representative titles were given. Specifically, it was found that although both environments were based on a similar motor task, the "equilibrium" environment involved a higher cognitive load and demanded more cognitive resources (attention, accurate movement, problem solving) compared to the second environment – "Backlash." Consequently, the "Backlash" VR environment was named low cognitive load virtual reality (LCL), whereas the "equilibrium" environment was named high cognitive load virtual reality (HCL).

2.7 Study Design

The study was approved by the ethical committee of the University of Haifa, Faculty of Social Welfare & Health Sciences. Each subject received an explanation of the study, signed an informed consent form to participate in the study, and then underwent a set of pain training tests and an introduction to VR environments. Ten minutes later, a battery of pain tests was performed to determine each participant's baseline sensitivity to pain. The battery included measuring heat and cold pain thresholds (TSA), sensitivity to noxious cold (time to pain onset, tolerance and intensity) and CPM, as explained above. All tests were conducted in a random order with an interval of five minutes between them. Immediately afterward, each subject went through three separate experimental conditions in a random order: A) LCL; B) HCL; or C) heat stimulation without VR (the control condition).

During each condition, the subject was exposed to tonic noxious heat stimulation (46.5°C, for 140 sec) applied to the medial part of the left ankle. Heat pain intensities (NPS 0–100) were reported six times: 10, 40, 70, 100, 130 seconds from the beginning of the heat stimulation, as well as 10 seconds after the stimulation was completed. The exposure to each VR environment lasted 120 seconds parallel to the heat stimulation, beginning 10 seconds following the commencement of the heat application (right after the first NPS report). Consequently, four NPSs were measured during participation in VR. Immediately after participating in each VR environment, subjects completed the self-feedback VR inventory, providing feedback regarding their experience in VR as commonly used in other VR studies (Yarnitsky et al., 2010).

2.8 Statistical Analyses

Descriptive statistics were used to describe subjects and study variables. Interrater reliability of the activity analysis form was examined by Intraclass correlations (ICC). Repeated measure ANOVA was performed to examine differences between the three study conditions in the extent of pain decrease. In order to examine differences between six measurements, the Bonferoni post hoc test was conducted. In order to examine interaction effect, repeated contrast was conducted. The maximal pain decrease from baseline was calculated for each study condition separately (i.e., Δ LCL, ΔHCL, ΔControl). The Spearman correlation test was performed to examine correlations between all pain measurers taken before the three study conditions and pain decrease following VR. Hierarchical regression was performed for examining the variables predicting pain decrease following VR. Results were considered significant at the 0.05 level. Findings are presented as mean±SEM.

3. RESULTS

All pain measures that were taken before the three study conditions are depicted in Table 1.

The mean (±SEM) scores of the self-feedback VR Inventory (1–5) were as follows: (1) following LCL: anticipation 3.8±.91; movement skills 3.9±.80; attention and cognitive inhibition 4.2±.64; physical effort 3±.87; (2) following HCL: anticipation 3.3±1.11; movement skills 3.1±.92; attention and cognitive inhibition 4.1±.85; physical effort 1.8±.85.

3.1 Effect of VR Participation on Pain Intensity – Within-Session Results

LCL Environment. The mean BL heat pain score taken before exposure to VR was 63.6±3.3; 30 seconds after the heat stimulus was administered, the mean pain score dropped to 32.8±3 (test 1), 29.0±2.7 (test 2), 30.0±2.9 (test 3), and 33.0±3.2 (test 4). In the last heat measurement following 120 seconds from the beginning of the stimulation and right after VR was discontinued (test 5), the mean pain score increased to 47.8±3.5 (RM ANOVA, $F(5, 305) = 73.54$, $p<.001$, $\eta^2=.55$).

HCL Environment. The mean BL heat pain score taken before exposure to VR was 65.6±3.3; 30 seconds after the heat stimulus was administered, the mean pain score dropped to 33.2±24.9 (test 1), 32.7±3.2 (test 2), 35.4±3.6 (test 3), and 33.6±3.6 (test 4). In the last heat measurement 120 seconds from the beginning of the stimulation and right after VR was discontinued (test 5), the mean pain score increased to 45.4±3.9 (RM ANOVA, $F(5, 305) =58.92$, $p<.001$, $\eta^2=.49$).

Table 1. *Descriptive values of pain parameters examined before the study conditions.*

	Heat pain intensity	Cold pain intensity	Cold tolerance (sec)	Cold threshold (Sec)	Cold threshold (°C)	Heat threshold (°C)	CPM
Mean±SEM	51.6±3.7	83.4±1.7	33.8±5.2	4.9±.4	9.3±.9	46.5±.4	28.9±2.4
Median	53.5	85	20.5	4.0	8. 6	47. 6	25
Range	0–100	40–100	6–180	1–19	0.3–25.6	36.9–50	0–70

Control Session. The mean BL heat pain score, was 63.9±3.2, which decreased to 48.4±3.2 at test 1 (RM ANOVA, $F(5,305) = 17.26$, $p<.001$, $\eta^2=.22$). During this session, across the following four measurements, pain ratings were similar: 48.0±3.3, 52.6±3.5, 56.4±3.7 and 55.3±4 (tests 2, 3, 4 and 5 respectively).

The maximal pain reduction was found to be between test 1 (BL) and test 2. Therefore, the difference between these two measures was calculated and the value, named ΔVR (Δ LCL= Δ low cognitive load VR), ΔHCL= (Δ high cognitive load VR, was used for further statistical analyses.

Table 2. *Mean ±SEM and F values of repeated measures for each study condition separately*.

	BL	Test 1	Test 2	Test 3	Test 4	Test 5	F
LCL	63.6±3.3	32.8±3	29.0±2.7	30.0±2.9	33.0±3.2	47.8±3.5	73.54**
HCL	65.6±3.3	33.2±24.9	32.7±3.2	35.4±3.6	33.6±3.6	45.4±3.9	58.92**
Control	63.9±3.2	48.4±3.2	48.0±3.3	52.6±3.5	56.4±3.7	55.3±4	17.26**

*** p<.001*

3.2 Effect of VR Participation on Pain Intensity – Comparison between Sessions

No significant differences were found between the three pain scores at baseline (RM ANOVA, $F(2,122) =.64$, $p=.53$). However, the reduction in pain intensity across the entire 140 seconds was significantly different between study conditions [$F(10, 610) = 14.53$, $p<.001$, $\eta^2=.19$]. Repeated contrast tests showed a significantly greater reduction in pain in VR conditions compared with control conditions between BL and test 1 [$F(2, 183)=14.97$, $p<.001$, $\eta^2=.14$). In addition, there was a significant increase in pain ratings in test 5 in VR conditions only ($F(2,183) =21.92$, $p<.001$, $\eta^2=.19$). (Figure 1).

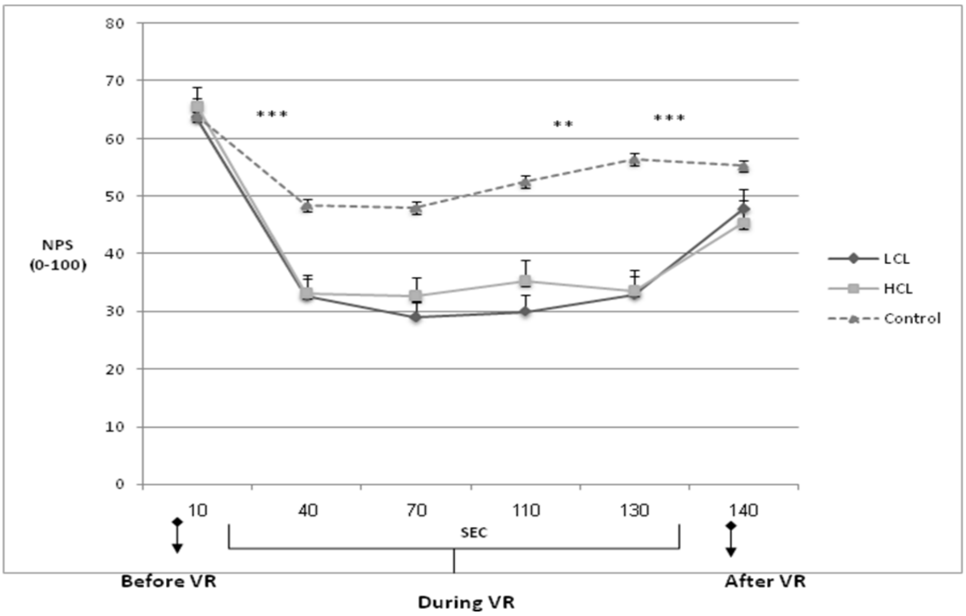
Correlations between the Battery of Pain Measures and Maximal Pain Decrease in Three Study Conditions. In the LCL environment, the Spearman correlation showed a negative correlation between ΔLCL and heat pain threshold ($r=-.27$, $p=.03$), and a positive correlation with heat pain intensity ($r=.33$, $p=.01$). In addition, there was a positive correlation between ΔLCL and CPM ($r=.39$, $p=.002$). In the HCL environment, only one correlation was found to be significant; this was between ΔHCL and CPM ($r=.40$, $p=.001$). All other correlations were not found to be significant.

3.3 Regression Analyses

In order to identify predicting variables for pain reduction, hierarchical regression analysis was conducted for each of the study conditions. The following variables were examined as possible predictors: gender, all pain measures, and four statements of self-feedback VR inventory (anticipation, movement skills, attention and cognitive inhibition, physical effort). In the LCL condition, hierarchical regression showed that gender explained 6.1% of the pain decrease variance, meaning that pain was less decreased in women than in men ($\beta=0.25$, $p=0.05$). CPM added another 7.5% of the explained variance, meaning that the extent of CPM predicted pain decrease ($\beta=0.28$, $p=0.03$). (See Table 3).

Hierarchical regression showed that gender predicted 10% of the explained variance in the HCL condition, as well, meaning that pain was less decreased in women than in men ($\beta=0.31$, $p=0.01$). CPM predicted 11.6% of the explained variance, meaning that the extent of CPM predicted pain decrease ($\beta=0.35$, $p=0.01$). In addition, two statements of the self-feedback questionnaire (anticipation + attention and cognitive inhibition) added another 20.2% of the explained variance, meaning that the higher the score for abilities of anticipation; attention and cognitive inhibition, the more the pain decreased ($\beta=0.40$, $p=0.001$). (See Table 4).

In the control condition, no predicting variables were found (F (4, 56) = 1.89, p=.13).



**p<.01, ***p<.001

Figure 1. *Heat pain intensity during three study conditions (mean±SEM). Asterisks represent differences between the two VR conditions and control within two adjacent time points. LCL=low cognitive load VR, HCL=high cognitive load VR.*

Table 3. *Hierarchical regression for predicting variables of pain decrease in an LCL environment.*

	Model 1			*Model 2*		
Variable	B	SE B	β	B	SE B	β
Gender	9.21	4.70	.25*	6.53	4.70	.18
CPM				.29	.13	.28*
		.061			.136	
F for change in R^2		3.84*			5.01*	

*p≤.05 Note: male:0, female: 1

Table 4. *Hierarchical regression for predicting variables of pain decrease in an HCL environment.*

	Model 1			*Model 2*			*Model 3*		
Variable	B	SE B	β	B	SE B	β	B	SE B	β
Gender	14.33	5.65	.31*	10.24	5.51	.22	14	5	.31**
CPM				.44	.15	.35**	.33	.14	.27*
A+CI							10.91	2.9	.40***
ant.							-5.03	2.19	-.24*
R^2		.10			.21			41.2	
F for change in R^2		6.42*			7.88**			9.95***	

*p≤.05 **p≤.01 ***p≤.001

Note: CPM: conditioned pain modulation; A+CI: attention + cognitive inhibition;

ant.: anticipation; male: 0, female: 1

4. CONCLUSIONS

The findings of the current study show that: (1) during VR with two different cognitive load tasks, pain ratings were significantly reduced with no difference in the reduction extent between the two virtual environments; (2) attention and cognitive inhibition, as well as anticipation, predicted pain reduction in the HCL environment only.

The effectiveness of the VR technique on pain relief was shown in various clinical pain conditions (i.e. Hoffman et al., 2004), and in the laboratory setting, demonstrated its alleviating effect on experimental evoked pain (i.e. Hoffman et al., 2003). Yet, the data is limited in examining the VR environment attributes that impact pain reduction. One study compared the effects of two different environments (warm and cold) on thermal pain intensities in healthy volunteers (Mulhberger et al., 2007). The authors hypothesized that a cold environment would reduce heat pain and vice versa. Nevertheless, this hypothesis was refuted when no differences were found in the effect of each environment on pain in both models. Law et al. (2010) examined whether increasing the demand for central cognitive processing (e.g., working memory and emotional control) involved in a distraction task would increase tolerance for cold pressor pain. They compared interactive versus passive distraction tasks via a VR-type helmet, and demonstrated that the effect of distraction on cold pain tolerance was significantly enhanced when the distraction task included greater demands for central cognitive processing.

The fact that the settings of these laboratory studies are diverse in many aspects points to the barriers that limit the generalization of conclusions from one study to another. The current study adds the knowledge that participation in VR reduces experimental pain intensity regardless of a specific cognitive demanded environment. While the fact that VR is an efficient pain distracter is not novel, the similarity of those two chosen environments in their ability to reduce pain was surprising. We believe that although a distinction in the cognitive load between the two tasks was verified, the cognitive load per se was not distinguished enough in this study. When we initially chose the VR environments we wished to minimize bias as much as possible by choosing similar tasks through the means of general presentation and motor activity. Even though the main parameter that was identified as diverse was the amount of cognitive load involved, it could be that the variation between environments was not sharp enough. Therefore, no difference in their impact on pain was found. Hence, the contribution of the cognitive load on pain reduction as was shown in previous studies (Eccleston & Crombez, 1999) cannot be ruled out due to the negative results of the present study; further studies are warranted in order to address this issue.

The present study also identified predictive factors affecting pain reduction during VR. Three predictors were identified. The first two predictors, including gender and CPM, are discussed in a previous publication (see: Demeter et al., 2014). The last and best predictor identified in this study as an efficient pain reducer under VR included the following cognitive components: (1) attention and cognitive inhibition and (2) anticipation. These cognitive components made an impact only when a high cognitive effort was required within the HCL VR environment.

The link between pain and cognitive performance has been previously observed in experimental and clinical settings (i.e. Coen et al., 2008). Attention constitutes the most studied cognitive component in relation to pain. While attending to a painful stimulus generally increases perceived intensity (Van Damme et al., 2010), previous studies have found that only a sufficiently attention-demanding cognitive task can divert attention away from pain (Eccleston & Crombez, 1999). The current study identified not only attention but also cognitive inhibition and anticipation as possible predictors for pain reduction during a task with a high cognitive load. Cognitive inhibition represents the ability to suppress irrelevant information and is considered a component of executive functions (EF). Other components of EF include the ability to formulate and maintain goals and strategies and to retain information for further processing (Connor & Maeir, 2011). To the best of our knowledge, there is sparse evidence relating to the link between EF and pain inhibitory control. One study evaluated these links with healthy volunteers exposed to a cold pain model (Oosterman et al., 2010); better cognitive inhibition (as measured by the Stroop test), but not other EFs, were found to be associated with less sensitivity with pain. Similarly, the current study showed that high perceived cognitive inhibition, as reported by the participant, predicted pain reduction.

Anticipation of action is another EF component (Barkley, 1997). When a task is performed repeatedly, it is more likely to be more automatically processed, which in turn reduces the accompanying cognitive load. This renders the task less effective in competing with pain for attention resources (Eccleston & Crombez, 1999). Our findings revealed that multiple task repetitions induce familiarization, which in turn enhances an individual's ability to anticipate more accurately the outcomes of his or her action. Thus, when a subject anticipated the outcome of his or her own actions, the subject was less distracted from pain.

Study limitations: The difference in cognitive load between the two VR environments was identified using a qualitative analysis process based on an activity analysis form as well as clinician's impressions. Further research is recommended in order to examine the cognitive load difference in quantitative measures.

In conclusion, this novel study obtained evidence for significant pain reduction during exposure to two VR environments as a function of the respective levels of cognitive demand. This aspect needs to be considered when customizing pain treatment protocols for patients coping with pain.

Acknowledgements: This study was supported by a grant from the Dean of the Faculty of Social Welfare and Health Sciences, University of Haifa, Israel, for an interdisciplinary research. Part of this study was submitted by the first author to the University of Haifa, Department of Occupational Therapy in partial fulfilment of the requirement for the master's degree.

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Integrative virtual reality therapy produces lasting benefits for a young woman suffering from chronic pain and depression post cancer surgery: a case study

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ABSTRACT

This case study was part of an evaluation of the BrightArm Duo Rehabilitation System for treating the effects of chronic upper body pain following breast cancer surgery. The subject was a 22-year old woman with burning and stabbing pain in the right upper arm. Training consisted of playing custom bimanual 3D games while seated at the gravity-modulating robotic table for 16 sessions over 8 weeks. Standardized assessments demonstrated a meaningful improvement in motor, cognitive and emotive domains with a statistically significant reduction in pain. Gains transferred to daily activities enabling the subject to resume full time employment, driving and socializing.

1. INTRODUCTION

The psychological, social and behavioral impact of cancer at a young age can be tremendous (Zebrack, 2011). As the number of young cancer survivors increase, their quality of life after cancer treatment becomes an important concern (Quinn, Gonçalves, Sehovic, Bowman, & Reed, 2015). With improved detection and progress in management of breast cancer (Kenyon, Mayer, & Owens, 2014), the survivors need improved rehabilitation approaches to address and overcome the resulting complications from that treatment. Depression and chronic pain in shoulder and arm following breast cancer surgery are highly prevalent and can lead to life-long psychological, cognitive and physical impairments. It is important to have rehabilitation techniques that can produce long lasting benefits for women, while being gradated in difficulty, interactive and fun.

Virtual reality (VR) offers benefits for other diagnostic conditions and provides a new and unique opportunity in the rehabilitation of women with breast cancer. VR analgesia, pioneered by Hoffman (Hoffman, Doctor, Patterson, Carrougher, & Furness, 2000) for burn wound care, has subsequently been used to reduce chemotherapy-related distress in women with breast cancer (Schneider, Ellis, Coombs, Shonkwiler, & Folsom, 2003), or anxiety for children with cancer (Gershon, Zimand, Pickering, Rothbaum, & Hodges, 2004). Virtual reality has great potential for use in acute and chronic pain by providing a non-opioid ‘virtual analgesic’ response (Triberti, Repetto, & Riva, 2014). This ‘distraction from pain’ response has also been studied for its ability to provide sustained benefits for pain control in cold pressor tests (Rutter, Dahlquist, & Weiss, 2009). Virtual reality therapy has been tried in breast cancer to alleviate symptoms during chemotherapy (Schneider et al., 2003). However, to the authors’ knowledge no clinical trials have been conducted to study VR effectiveness in breast cancer survivors with post-surgical chronic upper body pain and related depression.

The BrightArm Duo Rehabilitation System (Bright Cloud International, New Jersey, USA) is an experimental robotic platform that modulates gravity loading on the upper extremities (UEs). The ability to unload gravity makes it appropriate for individuals with weak arms and diminished ability to grasp, such as those suffering from chronic UE pain. BrightArm Duo uses VR to engage the patient in upper body bimanual integrative exercises that provide motor and cognitive training and affective relief. This integrative virtual rehabilitation has been found to be beneficial in prior BrightArm Duo studies of elderly individuals with chronic stroke residing in skilled nursing facilities (House et al., 2015). These earlier studies have shown benefits to cognition and depression reduction, which in theory could benefit breast cancer survivors with the same type of impairments. Thus, a feasibility study was conducted (N=6) to explore the feasibility of BrightArm Duo Rehabilitation System for the treatment of chronic pain in breast cancer survivor post-surgery, and who also have depression and cognitive deficits. The case described here was the youngest subject participating in that study.

2. METHODS

2.1 The BrightArm Duo rehabilitation

The BrightArm Duo Rehabilitation System consisted of a robotic rehabilitation table, two computerized forearm supports, a 27″ monitor, a laptop computer for the therapist, a remote clinical server and a library of custom integrative rehabilitation games. The library of custom games was developed in Unity 3D (Unity, 2016) for uni-manual and bi-manual motor (shoulder, elbow, grasp), emotive (depression) and cognitive (executive function, focusing, short-term and delayed memory, working memory and task sequencing) training. The subject interacted with these serious games through active arm movement and power grasp, both being tracked in real time. The forearms of the subject were placed onto low-friction supports outfitted with two 770 nm LED towers and a rubber pear bulb connected to an internal differential pressure sensor. The hand position was determined with better than 0.5 mm accuracy. Subject's grasp strength of the rubber pear was measured by the pressure sensor and communicated wirelessly to the laptop station at a data rate better than 40 packets per second. Each session, the system automatically adapted to the subject's forearm movement and grasp capabilities. Game difficulty, session duration, gravity unloading/loading (gravity assistance/resistance during training) on her upper extremity, were all gradated over the length of the training (House et al., 2015). Tilting upwards provided resistance when moving away from the trunk. Conversely, tilting downwards assisted weak arm movement.

Figure 1. *BrightArm Duo Table tilted upwards with two arm supports for user interaction and therapist laptop rendering Pick & Place game to the 27″ monitor. © Bright Cloud International Corp. Reprinted by permission.*

Figure 2 shows the screen images of the nine games used in the study. In *Breakout 3D*, the subject bounced a virtual ball toward an array of crates using paddle avatars. The game trained shoulder abduction/adduction or flexion/extension depending on the orientation of the crates, as well as focusing and executive function. The matching card games *Card Island* and *Remember that Card* trained short-term and delayed visual and auditory memory, grasp strength, shoulder abduction/adduction, and shoulder flexion/extension. For *Musical Drums*, the subject controlled drum stick avatars to strike a series of notes that drifted across (up to four) drums. This game trained focusing and motor control. The *Xylophone* game trained short-term auditory and visual memory by having the subject repeat a sequence of musical notes using mallet avatars. In *Pick & Place*, the subject grasped a ball from among multiple choices and then moved it to a fixed target of matching color, using shoulder flexion/extension or abduction/adduction arm movements. The game trained working memory and motor control as subject was asked to follow an ideal straight line to the target. Playing *Arm Slalom* induced shoulder rotations in order to guide a skier avatar through a downhill slalom course. In the *Avalanche* game, the subject controlled pickaxe and shovel avatars through grasp and arm movements. The task was to break and clear a series of ice walls so to free people trapped in a cottage. In *Treasure Hunt*, the subject used one or two shovel avatars to clear sand and uncover a series of buried treasures, before they were buried again by periodic sand storms.

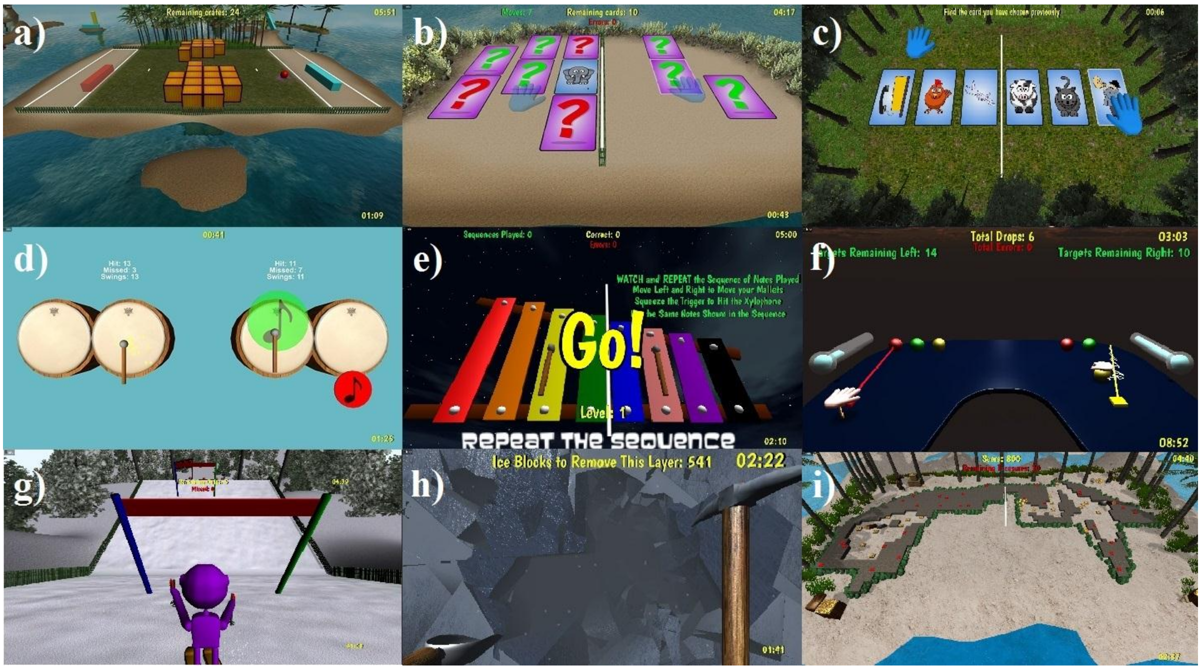

Figure 2. *Nine game screen images: a) Breakout 3D; b) Card Island; c) Remember that Card; d) Musical Drums; e) Xylophone; f) Pick & Place; g) Arm Slalom; h) Avalanche; i) Treasure Hunt. © Bright Cloud International Corp. Reprinted by permission.*

2.2 Training Protocol

The feasibility study followed a single subject A1-B1-A2-A3 design with training (B1) consisting of a total of 16 sessions, two sessions per week for 8 weeks. Standardized assessments of motor, cognitive and emotive state were performed pre-training (A1), post-training (A2) and at 8-week follow-up (A3). The training sessions progressed from 20 minutes to 50 minutes in duration, and the BrightArm Duo robotic table was tilted upwards progressively from a minimum of 0° (horizontal) at the start of the protocol to a maximum of 20° in the last training sessions (House et al., 2015). This corresponded to gravity unloading at the beginning of the therapy then progressively increased gravity loading as the subjects trained in later sessions. The Western Institutional Review Board, an independent board overseeing research involving human subjects, reviewed and approved the study protocol in accordance with Federal Guidelines. The subject was recruited at the University Pain Medicine Center (Somerset, NJ) and training took place at Roosevelt Care Center, a clinical facility in Edison, NJ in summer 2015. The subject received a $25 monetary compensation for each session attended however to the authors' knowledge this was not her primary reason for participation. The subject was genuinely interested in this experimental therapy to help manage her upper body pain symptoms.

2.3 Subject Characteristics

The subject was a 22-year old single woman of a mixed race, African American and White, with post-surgical chronic pain for the preceding 9 years. This chronic pain was localized to right upper arm and was burning, throbbing and stabbing in nature. She occasionally also reported pain in lower back, upper back, breast, hip and neck which was described as nagging. The subject reported that moving made her pain worse and nothing made it better. She had severe depression, difficulty socializing and had one suicidal attempt. As a consequence of her pain she kept her right arm in a sling which resulted in employment difficulties. She worked as a certified nursing assistant in home health care with hourly work that she would have to cancel many times due to pain. She was recruited from the University Pain Medicine Center where she followed up routinely with a pain medicine physician with a reported pain level of 6 to 8 on Numerical Pain Rating Scale (Paice, & Cohen 1997) and not undergoing any physical or occupational therapy at the time of her enrollment in the experimental study. The surgical procedure on her breast reported when she was 13 years old did not have any medical records for verification of diagnosis. She underwent lumpectomy of her right breast again in 2008 and cyst removal from left breast in 2007. She reported taking Tromodol 50 mg and Percocet 10 mg at pre-training. She had tried multiple therapies in the past as indicated in her clinical notes. These ranged from pain medications, to physical therapy twice a week for 10 weeks from January to April 2014, to home exercises,

2.4 Data Collection Instruments

Therapy session data (B1) included supported arm reach baseline on the BrightArm Duo table (as measured by overhead digital cameras used in tracking), power grasp strength baseline (as measured by a forearm support grasp sensor), heart rate and blood pressure. In addition B1 data included the number of active movements and grasp repetitions for each arm during a session, as well as game performance data (score, errors, completion time) collected during play. Pain was assessed using the Numeric Pain Rating Scale (NRS) administered verbally by the attending OT. This pain measure has validity in measuring cancer-related pain intensity (Paice & Cohen, 1997). Skin temperature was measured during the sessions with basis wristwatch that was worn on the subject's unaffected arm. Blood pressure and pulse were measured before and after each session using Omron 7 Series upper arm blood pressure monitor.

Occupational therapy evaluations were done pre-training, post-training and at 8 week follow-up by a blinded Senior Occupational Therapist (OT) consultant who was not training the subject. This OT evaluation involved assessment of upper extremity function using the Fulg-Meyer Assessment – Upper Extremity Section (FMA)(Duncan, Propst, & Nelson, 1983), the Chedokee Arm and Hand Inventory – 9 (CAHAI-9)(S. Barreca et al., 2004) for bimanual tasks and the Jebsen Hand Function Test (JHFT)(Jebsen, Taylor, Trieschmann, Trotter, & Howard, 1969) for hand function. Arm and hand range of motion were measured using mechanical goniometers, shoulder strength was assessed using wrist weights, grasp strength was measured with a Jamar mechanical dynamometer and a Jamar pinch meter. In addition the subject was assessed for her degree of independence in activities of daily living (ADL) involving the upper extremity, using the Upper Extremity Functional Index 20 (UEFI-20) (Chesworth et al., 2014).

Neuropsychological evaluations were done by a blinded research assistant under the supervision of a licensed clinical neuropsychologist pre-training, post-training and at follow-up. These were measures of depression severity, attention/concentration, processing speed, learning, memory, and executive function. The standardized measures used were the Beck Depression Inventory, Second Edition (BDI-II),(Beck, Steer, & Brown, 1996) the Neuropsychological Assessment Battery Executive Functioning Module (Generation subtest) (White & Stern, 2003), the Hopkins Verbal Learning Test, Revised (HVLT-R) (Brandt & Benedict, 2001), the Brief Visuospatial Memory Test, Revised (BVMT-R) (Benedict, 1997), the Trail Making Test A and B (TMT) (Reitan, 1958). Alternate test forms were used whenever possible to minimize test-taking practice effects. Raw scores were utilized in all data analysis. Both evaluating clinicians were blinded to the therapy methodology and scope.

At the end of weeks 4 and 8 of VR training, the subject rated her experience on a custom paper-based subjective evaluation questionnaire with ten questions. The questions were: 1) "The system was easy to use?"; 2) "Playing games with my affected arm(s) was easy?"; 3) "I had no pain or discomfort in my upper body?"; 4) "Instructions given to me were useful?"; 5) "Playing games with both arms was easy?"; 6) "I was not bored while exercising?"; 7) "The length of the exercising in a day was appropriate?"; 8) "There were few technical problems?"; 9) "I would encourage others to used it?"; 10) "I liked the system overall?". Each question was rated on a 5-point Likert scale, from 1 meaning "strongly disagree" (least desirable outcome) to 5 meaning "strongly agree" (most desirable one). The subject could add free form comments on the evaluation form.

3. RESULTS

3.1 Training Intensity

The subject exercised a total of 20,130 active arm repetitions and 7,020 hand grasps. The BrightArm Duo tilt was gradually increased from 0° to 20° upwards over the study. Figure 3a show active arm repetitions increased from about 320 in session 1 to over 1,500 repetitions in session 16 with peak activity around session 5 and 11. Hand grasps increased from 45 in session 1 to 971 by session 16. The intensity of play increased with session number as well. If session length is normalized to maximum duration of 51.2 minutes, arm movement and hand grasps would increase along a slope of 878 (p=0.18) and 1,011 (p<0.001) repetitions between session 1 and 16. The subject played a total of 412 games over a total of 567 minutes. The exercise length steadily increased from 21.2 minutes (session 1) to 51.2 minutes (session 16). Both game difficulty and subject performance increased over the study. Figure 3b illustrates how composite games rose from 43 (session 1) to 65 (session 16). The linear regression fit of the data points yielded a statistically significant trend line (p<0.001) corresponding to a 22 point increase in average game score from about 47 points in session 1 to about 69 points in session 16.

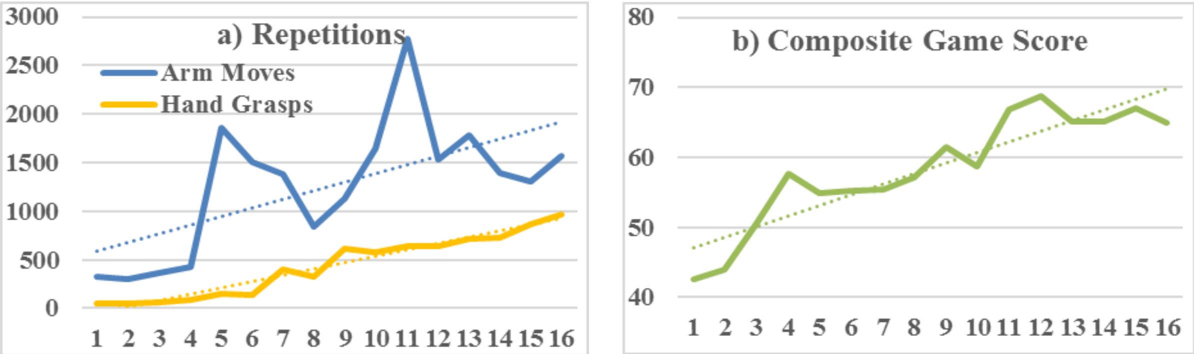

Figure 3. *a) Arm and hand repetitions and b) composite game score by session number for the cancer survivor experiencing post-surgery chronic pain. © Bright Cloud International Corp. Reprinted by permission.*

3.2 Pain and Skin temperature outcomes

The subject's reported pain and skin temperature was captured every session. Figure 4a illustrates the maximum upper extremity pain on the 10 point Numerical Pain Rating Scale by session number. As seen by the statistically significant trend line (p=0.01), there was marked reduction in reported pain of 4.4 points over the course of the study. Figure 4b plots the average skin temperature by session number as measured at the wrist of the subject's unaffected arm. The linear regression fit of the data points yielded a statistically significant trend line (p=0.001) corresponding to a 10.25°F increase in skin temperature over the 16 sessions. This is indicative of increased blood flow to the upper extremity in response to increased use of the affected arm.

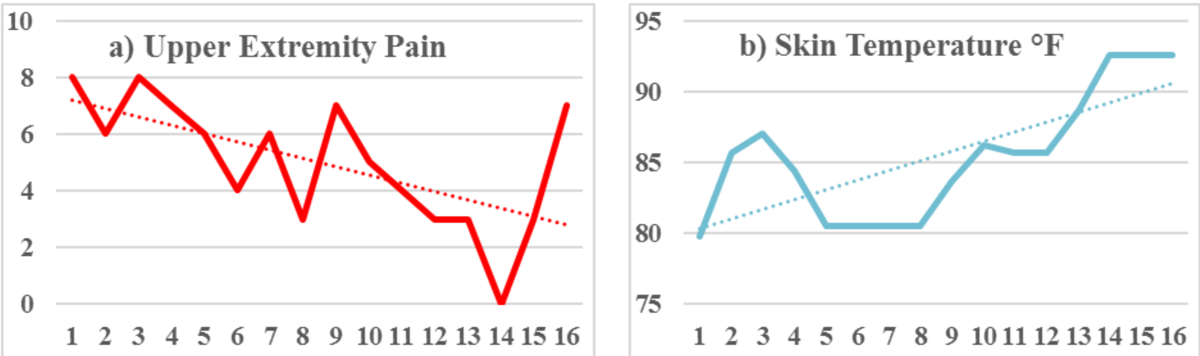

Figure 4. *a) Maximum upper extremity pain and b) affected arm skin temperature by session for the cancer survivor experiencing post-surgery chronic pain. © Bright Cloud International Corp. Reprinted by permission.*

3.3 Upper extremity active range of motion

The subject's range of motion was evaluated for the affected and unaffected arms at pre-training (A1), post-training (A2) and follow-up (A3). The elbow and finger values were within normal limits. In Table 1, 10 of 12 range of motion measures improved at A2 and A3 relative to A1. The affected arm maintained substantial gains at A3: Abduction (111°), Flexion (89°), Adduction (40°), External Rotation (31°), and Extension (19°). The unaffected arm improvements were more modest at A3: Flexion (16°), Abduction (10°), Extension (9°) with Internal Rotation moderately decreasing (20°). The minimal clinically important difference (MCID) is 8° for shoulder range of motion improvement (Salamh & Kolber, 2012).

Table 1. *Shoulder range of motion (degrees) for the post-surgery cancer survivor experiencing chronic pain. © Bright Cloud International Corp. Reprinted by permission.*

	Affected Shoulder					Unaffected Shoulder				
Variable	A1	A2	A3	A2-A1	A3-A1	A1	A2	A3	A2-A1	A3-A1
Flexion	58	150	147	+ 92	+ 89	132	146	148	+ 14	+ 16
Extension	23	73	42	+ 50	+ 19	58	77	67	+ 19	+ 9
Abduction	27	157	138	+ 130	+ 111	140	148	150	+ 8	+ 10
Adduction	0	56	40	+ 56	+ 40	33	50	40	+ 17	+ 7
Internal rot.	38	55	40	+ 17	+ 2	70	68	50	– 2	– 20
External rot.	50	78	81	+ 28	+ 31	82	77	75	– 5	– 7

3.4 *Upper extremity strength*

Table 2 lists arm and hand strength for the affected and unaffected arms pre-training (A1), post-training (A2) and follow-up (A3). All ten strength measures improved or remained the same as compared to A1. At follow-up, the gains in grip strength compared to pre-training were 231.3 N and 97.9N for the affected and unaffected hands, respectively. These results are 200% to 400% the MCID of 49 N for hand grip (Lang, Edwards, Birkenmeier, & Dromerick, 2008). At follow-up, the affected and unaffected hand two-finger pinch improved 29.8 N and 20.0 N, respectively and the 3-jaw pinch improved 36.5N for both hands, compared to pre-training. The affected shoulder strength had an impressive gain from 4.4N at A1 to 31.1N at A3, a 700% increase. The unaffected shoulder strength improvement was from 31.1N to 44.5N represents a more modest 40% increase.

Table 2. *Hand and arm strength for the post-surgery cancer survivor experiencing chronic pain. © Bright Cloud International Corp. Reprinted by permission.*

	Affected Shoulder					Unaffected Shoulder				
Variable	A1	A2	A3	A2-A1	A3-A1	A1	A2	A3	A2-A1	A3-A1
Hand Grip	68	262.4	299.4	+194.4	+ 231.3	115.7	218.0	213.5	+ 102.3	+ 97.9
Tip Pinch	0.0	31.1	29.8	+ 31.1	+ 29.8	11.1	23.6	31.1	+ 12.5	+ 20.0
3 Jaw Pinch	4.4	46.7	40.9	+ 42.3	+ 36.5	16.9	34.7	53.4	+ 17.8	+ 36.5
Ant. Deltoid	4.4	22.2	31.1	+ 17.8	+ 26.7	31.1	31.1	44.5	0.0	+ 13.3
Lat. Deltoid	4.4	22.2	31.1	+ 17.8	+ 26.7	31.1	31.1	44.5	0.0	+ 13.3

3.5 *Upper extremity functional assessments*

Functional assessments also improved at post-training (A2) and follow-up (A3) relative to pre-training (A1). Fugl-Meyer Assessment scores were 47 (A1), 58 (A2) and 56 (A3). The 11 and 9 point improvement at A2 and A3 respectively meet the MCID criteria of 9 points (Arya, Verma, & Garg, 2011). CAHAI-9 scores were 50 (A1), 63 (A2) and 63 (A3). The improvement of 13 points at A2 and A3 is twice the MCID of 6.3 points (Barreca, 2015), and is indicative of improved ability to perform bimanual ADLs. The metric UEFI-20 measurements were 18 (A1), 58 (A2) and 42 (A3). The improvement of 40 and 24 points at A2 and A3 were three to five times the MCID of 8 points (Chesworth et al., 2014). The JHFT for the affected hand was 79 (A1), 35 (A2) and 39 (A3) seconds. The subject was able to complete the manual tasks of JHFT in half the time post-training, and the speed improvement was maintained at follow-up.

3.6 *Cognitive and emotive outcomes*

Table 3 lists emotive and cognitive measures evaluated pre-training, post-training and follow-up. There was a notable reduction in depression severity of 16 points (A2) and 6 points (A3). Both values were above MCID of 5 points for BDI-II (Hiroe et al., 2005). The Trail Making Test Part B showed a reduction in time from 128 seconds at A1 to 49 seconds at A3. This was indicative of improved attention and processing speed. HVLT-R which measures verbal learning and memory was one cognitive measure that showed a systematic decline from

22 points at A1, to 20 points at A2, and 16 points at A3. This was offset by an increase in word generation from 5 at A1, to 6 at A2 and 9 at A3. There was a systematic increase BVMT-R, from 13 points at A1, to 18 points at A2 and 20 points at A3, indicative of improved visuo-spatial memory.

Table 3. *Emotive and cognitive outcomes for the post-surgery cancer survivor experiencing chronic pain. *indicates sign reversed so all positive differences in table indicates improvement. © Bright Cloud International Corp. Reprinted by permission.*

Variable	A1	A2	A3	A2-A1	A3-A1	Variable	A1	A2	A3	A2-A1	A3-A1
BDI-II	37	21	31	*+ 16	* + 6	HVLT-R	22	20	16	– 2	– 6
TMT-A	20	22	22	* – 2	* – 2	BVMT-R	13	18	20	+ 5	+ 7
TMT-B	128	66	49	* + 62	* +79	Word Gen	5	6	9	+ 1	+ 4

3.7 Subject Attendance and Testimonial.

The subject completed the 16 sessions of the protocol over a period of 9 weeks. She postponed two sessions early on due to back pain related to work and unrelated to BrightArm training. She reported no side-effects from the VR therapy such as cyber sickness or headache. The subject evaluated the system by answering the ten questions. The average response was 3.6/5 at the two sampling times (week 4 and week 8). The lowest scores were for the questions: “I had no pain or discomfort in my upper body?” (1.5); “Playing games with my affected arm(s) was easy?” (2.0); “I would encourage others to used it?” (3.0); “The length of the exercising in a day was appropriate?” (3.5). The responses averaged a rating of 4 between week 4 and 8 for the questions: “The system was easy to use”; “Playing games with both arms was easy?”; “There were few technical problems?”; “Instructions given to me were useful?”. The highest evaluation score was 5.0/5 for the questions: “I was not bored while exercising?” and “I liked the system overall?” which shows excellent technology acceptance of the BrightArm Duo.

At follow-up (A2) the subject was asked if she would provide a testimonial. In compliance to IRB Human Subject’s Regulations her identity is not disclosed, although she included her name in the email sent in late May 2015. This email is included here with subject’s approval, as it provides her opinion on the impact that the experimental therapy had on her life.

“*I’ve just completed my 8 weeks of physical therapy. This therapy section helped me tremendously. Before I started this therapy my right arm had no use me and there was so much pain! There were things I couldn’t do like driving, getting dressed, taking a shower, playing with my nephew....I was working on and off, I couldn’t hang out with my friends, my life basically stopped, and it was very depressing. But now I’m driving, I’m back working full time, I’m catching up with friends AND there’s no pain. I’m extremely happy with the results, this is my third time trying therapy for my arm and this the only one I saw results from. The therapy sessions consist of games....yes you are literally sitting in a chair in front of a computer playing games, though they were challenging it was also very fun, well for me it was. Dr. Burdea and his team gave me back my life because I thought it was over literally. I recommend everyone that’s having this problem to try this therapy session, it works tremendously and it is fun (did I mention it’s actually games you play on a computer) yes and everyone is very friendly. So thank you Bright Cloud International.*”

The subject was referring to BrightArm Duo in the physical therapy reported in this testimonial. She has compared VR games to the traditional physical therapy she had undergone in the past which did not work for her. The immersive games induced bilateral high repetitions and engaged the participant with rewarding feedback for effort. These features made the rehabilitation training with BrightArm Duo distinctly different from her prior traditional therapy

4. CONCLUSIONS

Childhood cancer survivors have an increased risk of complications later in life and rehabilitation with better outcomes will greatly improve the quality of life in these women (Kenney et al., 2004). In this study, the 22-year old female subject showed marked reduction in shoulder and arm pain of 4.4 points on the NRS scale which is much higher than the MCID of 2.17 for NRS established for people with surgical and post-surgical shoulder pain (Michener, Snyder, & Leggin, 2011). This is an encouraging finding considering the impact of VR therapy on chronic pain in other conditions such as fibromyalgia has shown no benefits for pain intensity (Garcia-Palacios et al., 2015). However, the benefits of VR therapy in cancer related pain during acute painful procedures, hospitalization and chemotherapy has been studied and shown to be beneficial (Chirico et al., 2016). Visual distraction has been one of the theories put forth for explaining these beneficial effects on pain (Triberti et al., 2014). Although, in this study, the positive effect on pain intensity cannot be completely attributed to the phenomenon of visual distraction. As reported in other literature (Loreto-Quijada et al., 2014), the distraction from pain could be insufficient to cause the accompanied improvements on motor and cognitive aspects of function measured at post-training and maintained at 8-week follow up. It is also likely that the 16-session protocol used in this study resulted in better outcomes than the 10-session protocol reported in other studies of VR in chronic pain of fibromyalgia (Botella et al., 2013).

Garcia-Palacios et al. (28) reported no benefit of VR therapy on depression in people with chronic pain due to fibromyalgia, whereas in this study, the depression scores decreased by 16 points on the BDI-II, which is a 32% improvement. The MCID for depression varies with initial severity (Button et al., 2015) and has been estimated to be 32% for individuals with prolonged depression which fits the profile of the subject in this study. A recent review by Chirico et al., (2016) (Chirico et al., 2016) summarizes the benefit of VR therapy in cancer on psychological variables such as state anxiety and painful procedures, the results of the present case study open the possibility to understand the impact of VR therapy in other variables such as depression. Chirico et al. (2016) also recommend including bio physiological variables in VR therapy research in cancer using biosensors for understanding physiological responses to the training. In this study, biosensors at the wrist of the unaffected arm showed a 10.25°F increase in skin temperature with the over the course of the 16 sessions conducted in the same indoor therapy room. This interesting finding is indicative of an increased thermal response during exercise that is likely during moderate to high intensity exercise (Neves et al., 2015) and was associated with improved outcomes in the subject. This may indicate increased blood flow to the arm with a beneficial effect for overall health of the arm (González-Alonso et al., 2015).

An average of 1,260 active arm repetitions and 440 hand grasps per session for the subject over the course of 16 sessions is an important characteristic of the BrightArm Duo therapy. This large number of induced arm repetitions has previously been reported (House et al., 2015) to benefit elderly stroke survivors in the chronic phase. The substantial benefits of this intensive therapy are indicative of application for chronic cancer pain populations as well. All standardized measures in this case study of range of motion, strength, UE function, attention, and memory improved at post-training. With the NRS pain level of 6 and 7 pre-training, the subject was unable to move her right arm and post training the regained range of motion in the arm along with simultaneous distraction from pain has shown to be the right combination of therapy for her. As seen from her own testimonial, the subject was able to transition to a full time job and returned to driving giving her maximal functional independence much desired at her young age.

A remarkable finding in this case study was that at 8-week follow up (A3) the majority of gains remained higher than A1, with no VR training after A2. The subject did not report playing any form of videogames during the no-VR phase and enjoyed reading and socializing for recreation. The maintenance effect with VR therapy has been shown in prior studies in 48 hour follow-up (Schneider et al., 2003), however a 8-week follow up has not been reported. The study of VR maintenance effect for rehabilitation therapy programs is as critical for chronic pain conditions as it is for rehabilitation of conditions such as stroke (Viñas-Diz & Sobrido-Prieto, 2015). This longitudinal study is lacking in the current VR literature related to cancer treatments (Chirico et al., 2016). This case study was able to establish the feasibility of a longitudinal study protocol to study these maintenance effects of VR therapy in chronic pain and depression.

This study, part of an n=6 feasibility evaluation of the BrightArm Duo system for upper body chronic pain, has obvious limitations to generalizability. However, the information detailed in this case study brings forth the qualitative aspects associated with BrightArm Duo training especially in younger individuals and helps examine the feasibility of the VR therapy in this sample of cancer survivors. The therapists can benefit greatly with an in-depth study of successful cases using BrightArm Duo system in rehabilitation to maximize benefits for their clients. In conclusion, initial findings demonstrate a meaningful reduction in chronic pain and physical, cognitive and psychological improvement for a young female subject. These suggest a need for controlled studies in young breast cancer survivors with pain and depression associated to post-surgical treatment of breast cancer.

Acknowledgements: Research reported here was supported by grant 1R43DA032224-01 from the National Institutes for Health/NIDA. We wish to thank Abby Eisner OT and Daniel Saldana who performed the clinical evaluations and Ms. Noreen Rana, the clinical coordinator for the study.

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Does mixed reality influence texting while walking among younger and older adults?

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ABSTRACT

Young and older adults have difficulties in performance of an additional task while walking (dual task). This feasibility study investigates the dual task costs of texting on a mobile phone and walking among young and older adults, as well as the potential of a mixed reality app, which projects the real world onto the background of the mobile display, to modify these costs. Seven young (age 26.4±4.5 years) and 7 older (age 69.9±3.9 years) adults were asked to walk while texting on a custom-written mobile android app (with and without mixed reality display), as well as to perform each task (walking, texting) separately. Preliminary results show that dual task interference of both tasks is similar in both groups. Using a mixed reality display does not modify these costs, but does affect the subjective experience of the groups differently. This may be due to different levels of familiarity with mobile phone use in the two groups. Additional data is currently being collected.

1. INTRODUCTION

Functional locomotion involves performance of multiple (two or more) concurrent tasks, i.e. dual tasking. Additional cognitive load changes locomotion patterns in healthy and, particularly in older adults or clinical populations (Yogev-Seligmann, Hausdorff, & Giladi, 2008). For example, healthy young adults decrease gait speed while performing another task (Abernethy, Hanna, & Plooy, 2002), especially when talking (Plummer-D'Amato, Altmann, & Reilly, 2011).

Due to advances in technology, people increasingly perform a novel type of dual task during walking – using a smartphone. Indeed, these devices have become an inseparable part of our daily life; we use smartphones to text, take pictures or browse the web while performing other activities of daily life, notably walking. For example, pedestrians who talk on the phone exhibit more unsafe behaviors, potentially endangering themselves and others when crossing roads (Nasar, Hecht, & Wener, 2008; Neider, McCarley, Crowell, Kaczmarski, & Kramer, 2010). Texting while walking, in comparison to talking while walking, generates stronger interference with gait (Lopresti-Goodman, Rivera, & Dressel, 2012) due to the added visuo-motor distraction. However, research on the effect of texting on walking began only recently. Indeed, young adults who text while walking experience changes in gait including a slower pace and altered spatio-temporal stability of the center of mass, specifically in the frontal plane (Kim, Park, Cha, & Song, 2014; Lamberg & Muratori, 2012; Lim, Amado, Sheehan, & Van Emmerik, 2015; Marone, Patel, Hurt, & Grabiner, 2014; Plummer, Apple, Dowd, & Keith, 2015). Only one study evaluated performance of older adults while using a smartphone concurrently with walking (Takeuchi, Mori, Suzukamo, Tanaka, & Izumi, 2016). However, this study did not measure gait speed and did not use a texting task but rather a game played on the mobile phone.

A possible solution to the problem of distraction during use of a mobile device involves the addition of information from the smartphone user's surroundings onto the mobile phone display. This solution may enable the user to continue to look at the phone with increased awareness of the environment. This is an example of "Mixed Reality" (MR), a location along Milgram & Kishino's (1994) reality-virtuality continuum which involves the merging of real and virtual worlds. Products such as Google Glass and Microsoft's Hololens are leading examples in this evolving field, enabling users to remain present in their environment while interacting with a mobile device. For example, a simple solution for writing text while walking is to use the mobile device's camera to display the actual field of view while still being able to use the keyboard; the real world is projected onto the smartphone screen as shown in Figure 1.

Figure 1. *An example of an off-the-shelf application (Type n walk, www.type-n-walk.com) projecting the real world view captured by the smartphone camera behind a data layer (e.g., used for writing text).*

Although such a solution has considerable potential for decreasing texting-related pedestrian accidents, its effect on walking is largely unknown. Furthermore, the effect of texting with or without the use of MR technology may vary between young and older adults, and may pose an additional barrier to learning in older adults, further impairing their performance. Older adults tend to be slower, more variable and less accurate in their performance of fine motor skills (Welford, 1962), as well as in their ability to learn novel fine motor tasks such as precision grip, computer typing, and different finger and arm movements (Voelcker-Rehage, 2008). The performance decline in fine motor skills in older adults has been explained by a multitude of factors such as decreased visual and auditory perception, psychomotor speed, visuo-motor coordination and executive control (Birren, 2013; Krampe, 2002). When presented with a task such as mixed-reality texting performed concurrently with a gross motor task (walking), older adults may not achieve the required performance level needed to engage with the real world (e.g., walk fast enough to cross a road). Given the pervasiveness of mobile technology, it is important to evaluate the ability of older adults to use mobile devices concurrently with performing daily tasks such as walking.

The overall objective of this study is to evaluate the effect of texting with and without MR on walking in real life situations. Specifically, the objectives of this paper are:

1. To compare the effects of texting while walking on walking and texting speed in young and older adults.
2. To evaluate the subjective and objective effects of using mixed reality while texting and walking in young and older adults.

2. METHODS

2.1 Participants

Participants were recruited for the study in two groups according to age; 20-45 years and >65 years. In order to participate, they were required to own and use a smartphone for writing text messages (among other uses) for >1 year and, in the case of the older adults, were required to score > 19 on the Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005) to exclude moderate cognitive impairment. Participants were excluded if they had orthopedic or neurological impairment affecting locomotion, any pain during walking, or an uncorrected visual or hearing impairment, used an assistive device to walk (cane, walker, etc.) or reported an inability to text or read while walking (e.g., due to dizziness).

2.2 Experimental tasks and apparatus

2.2.1 Experimental apparatus

- *Mixed Reality texting application*. A custom-written Android application was used, enabling the participants to input text on screen while being presented with the primary camera's live stream in the background. The application was developed in order to enable standardization of the texting task across participants, i.e. use the same phone, keyboard and avoid incoming private text messages or other pop-up messages during the experiment, in addition to providing complete information regarding texting performance (deletions, speed, etc.). The Android app was run on a Samsung Galaxy S4 smartphone, running Android 4.2.2 (JellyBean). Dimensions of the phone were 136.6 x 69.8 x 7.9 mm, 5.0″ screen, and mass 130 g. The phone was equipped with a 13MP, 4128x3096 pixel camera. Text to be typed by the participant was presented on the upper part of the screen and the user's input was displayed below it (Figure 2). In the background, it was possible to display the camera's input stream such that the field of view was not obstructed by the phone. In conditions where MR was not used, the background was left black. The app logged typing output (timing of every character typed) which was written to a text file and exported via e-mail for offline processing.

- *Mobility Lab sensor system.* Walking kinematics were recorded with a commercial sensor system (Mobility Lab, APDM Inc., Portland, OR) using 3 OPAL sensors (48.5 x 36.5 x 13.5 mm, 22 grams each) mounted on the participant's shanks (2 sensors) and on the lumbar spine (one sensor; Figure 2, right panel). Mobility lab sensors provide 6 degrees of freedom data (three-dimensional acceleration and three-dimensional gyroscopic data) recorded at 128 Hz. Mobility Lab sensors have been used to detect gait and balance performance in healthy individuals as well as in people with neurological conditions (Baston, Mancini, Schoneburg, Horak, & Rocchi, 2014; Weiss et al., 2015).
- *GoPro camera.* Navigation in the environment was documented using a GoPro Hero2 camera affixed to the participant's sternum (Figure 2, right panel). The camera's wide field of view (127-170 degrees) enabled documentation of events during testing (e.g., people crossing the path, sounds).

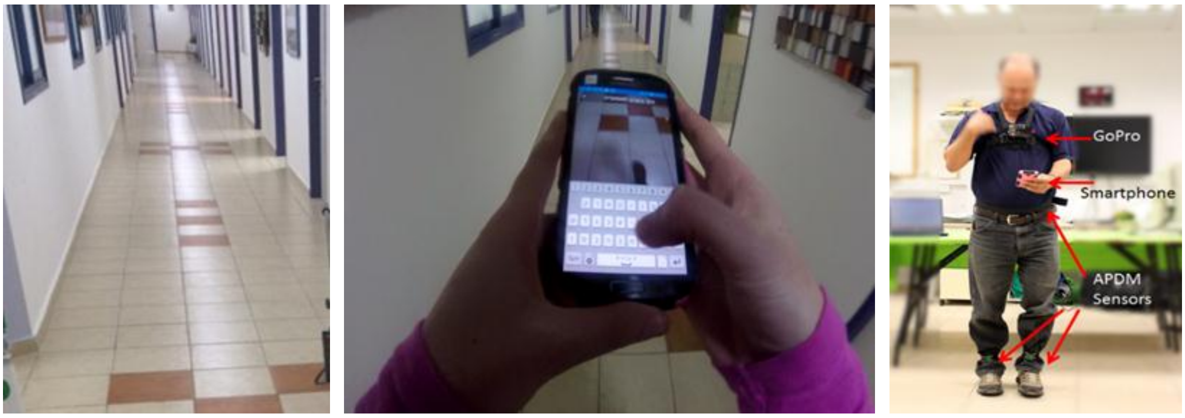

Figure 2. *Left panel: setting of walking conditions, a quiet, well-lit university corridor. Center panel: the MR app main screen. During the mixed reality condition, the back camera view is projected behind the text (view shown in this figure). In other conditions, the background is blackened. Right panel: experimental setup. Three APDM sensors are attached to the ankles and at the hips. A GoPro camera is attached to the chest, pointing forward.*

2.2.2 Additional assessments

- *Trail Making Test (TMT*) is a test that assesses visuo-motor scanning, divided attention and cognitive flexibility. Individuals are requested to draw a line to connect a series of characters that alternate between numbers and letters (i.e., 1-A-2-B-3-C, etc.). Time to complete the task is measured. This is a widely used test that was found to be predictive of falls among older adults (Reitan & Wolfson, 1995; Tombaugh, 2004).
- *Montreal Cognitive Assessment (MOCA)* is a screening test that was developed to detect mild cognitive impairment. The test screens cognitive abilities in seven domains (e.g., executive functions and memory) with scores ranging from 0 to 30. The test was found to be reliable and sensitive to detect mild cognitive impairment (Nasreddine et al., 2005).
- *Timed-Up-and-Go (TUG) and TUG-cognitive.* The TUG measures the time taken by a participant to stand up from a standard chair, walk 3 meters, turn, walk back and sit down in the chair (Shumway-Cook, Brauer, & Woollacott, 2000). This test was found to be valid and reliable for predicting falls among older adults (Schoene et al., 2013). Participants in the study completed the TUG as well as the TUG-cognitive, where a subtraction (by 7) task was performed concurrently.
- *Motor tapping.* Maximum typing speed was assessed by asking participants to continuously type a single character (space) as fast as they could on the mobile phone in the absence of additional visual input.

2.3 Procedure

Participants were tested during a single one-hour session. After signing informed consent forms, participants were asked to complete a demographic questionnaire including details about their mobile phone usage. Then, they performed the TMT, TUG and TUG-Cognitive, and the older adults also completed the MoCA. The experiment took place in a quiet, well-lit indoor university corridor (Figure 2, left panel). This corridor was selected since its lighting distribution minimized glare and reflections. Participants were asked to walk along a 30-meter path for one minute, in one of three conditions: walking while holding the phone in their hand (Single Task (ST)), walking while texting (Dual Task (DT)), and walking while texting with MR (i.e., with the camera view in the background (MR)). Additionally, participants were asked to text for 1 minute while standing still. The order of the four conditions for each participant was selected using block randomization. During the texting tasks participants were required to copy simple 3-word sentences in Hebrew (their native language), similar to text messages, presented on the top part of the screen (e.g., “I wore a sweater to work”). Order of the sentences was randomized, and different sets were used for every walk condition to avoid memorization. Autocorrect was turned off. Finally, maximum typing speed was measured by typing a single character on the mobile phone (motor tapping).

Following testing, two visual analog scales (VAS), 10 cm black lines anchored by two end points on a white card, were presented to the participants asking them to cross the line to show how much they used visual input via the smartphone screen while walking (VAS 1: “How helpful was the background screen presentation (when presented)?” not at all→very helpful), and whether they would use such an app in real life (VAS 2: “How likely are you to use such an app in the future?” not likely at all→very likely).

2.4 Outcome measures and data analysis

Data analysis was performed using custom-written Matlab code (Matlab R2015, Natick, MA). Data from motion sensors on shanks and hips was filtered using a second order Butterworth filter (dual-pass, 70 Hz low-pass) and gait events (heel strike, toe-off) and turns were identified according to the method described by Simoes et al. (2011); Timing of heel strike was identified from peaks in vertical acceleration signals of the shank sensors. Stride time was calculated as the temporal difference between consecutive peaks in the same leg. Stride length was calculated using data from gyroscopes in the shank sensors. Angles of the shank in the sagittal plane were identified from gyroscopic data of the shank sensor at the moment of heel strike (separately for the right and left leg heel strike). According to the law of cosines, the joint angle ($\alpha + \beta = \gamma$) relates to leg length (l) and step length (s) in the following way:

$$s = l * \sqrt{2 - 2cos\gamma} \tag{1}$$

The same procedure was performed for two consecutive steps, and step lengths were summed to obtain stride length. Although limited by not taking the knee angle into account, this method has been used with wearable sensors in both healthy and clinical populations and results in excellent correlation coefficients when compared to gold-standard motion capture systems (Horak, King, & Mancini, 2015; Mariani et al., 2010). Stride length and time were used to calculate gait speed. Finally, covariance of gait speed, stride length and stride time were calculated for each subject in every condition.

Data of texting performance was extracted from Excel files produced by the mobile app. Texting speed (measured in Characters Per Minute, CPM) was calculated by dividing the time required to write each sentence by the number of characters typed including spaces. This value was averaged across all sentences typed within a single condition. Similarly, the maximum tapping speed was calculated for the typing speed condition. Texting accuracy was measured using the Levenshtein distance, a metric evaluating the minimum number of single-character edits (i.e., insertions, deletions or substitutions) required to change one string of characters into another (Levenshtein, 1966). The final typed sentence was compared to the displayed sentence, and the mean Levenshtein distance for all sentences in a specific condition was calculated. The number of deletions performed to obtain the final text was calculated separately, as deletions during text writing are usually undetected when only final strings are available, but may also influence accuracy and speed of text writing.

Dual task cost (DTC) of gait speed, stride length and stride time, as well as texting speed were calculated using the following formula (Plummer & Eskes, 2015):

$$DTC(\%) = 100 \cdot \frac{Single\ task\ performance - Dual\ task\ performance}{Single\ task\ performance} \tag{2}$$

Subjective user experience for using the MR app was evaluated by calculating the position of responses on the visual analog scales, dividing by total length of line and multiplying by 100.

Due to the small sample size, non-parametric tests were used to compare gait parameters (mean gait speed and DTC) and texting (mean typing speed and DTC) for between group (Mann-Whitney) and within group (Wilcoxon) comparisons across the various conditions: single task (ST), dual task (DT) and dual task with mixed reality (MR). It should be noted that data for cycle time covariance for one older subject was removed following outlier analysis.

3. RESULTS

3.1 Feasibility of protocol

To date, seven young and seven older adults completed the study protocol. None of the participants reported difficulties with the protocol and all were able to complete all conditions. In addition, no adverse events were observed.

3.2 Participants characteristics

Participant characteristics are described in Table 1 below. Older adults have less experience in texting compared to younger adults as most of them (71.4%) reported that they text less than 10 times a day as opposed to the younger group where only 28.6% reported texting in low frequency. In addition, older adults reported that they rarely tend to text while walking. No significant between-group differences were found in TUG, TMT-B and maximum finger tapping speed.

3.3 Between group comparisons

Gait and texting parameters across conditions, of both groups, are presented in Table 1 and figures 3-5. The younger group typed significantly faster than the older group during the three experimental conditions (ST; U=5.0, p=.01; DT; U=6.0, p=.02; MR; U=4.0, p=.009). No significant group differences were found in gait speed during all conditions and in DTCs of gait speed and typing speed.

3.4 Within group comparisons

As compared to ST, both groups walked significantly slower during the DT (younger; z=-2.4, p=.02; older; z= -2.2, p=.03) and MR (younger; z=-2.2, p=.03; older; z= -2.4, p=.02) conditions. There were no significant differences in gait speed between DT and MR conditions for either group.

As compared to ST, both groups typed significantly slower during the DT condition (younger; z=-2.4, p=.02; older; z= -2.4, p=.02). As compared to ST, only the younger group typed significantly slower during the MR condition (z=-2.2, p=.03). There were no significant differences in typing speed between the DT and MR conditions for either group. In addition, there were no significant differences between DTCs of gait speed nor in DTCs of typing speed for either group.

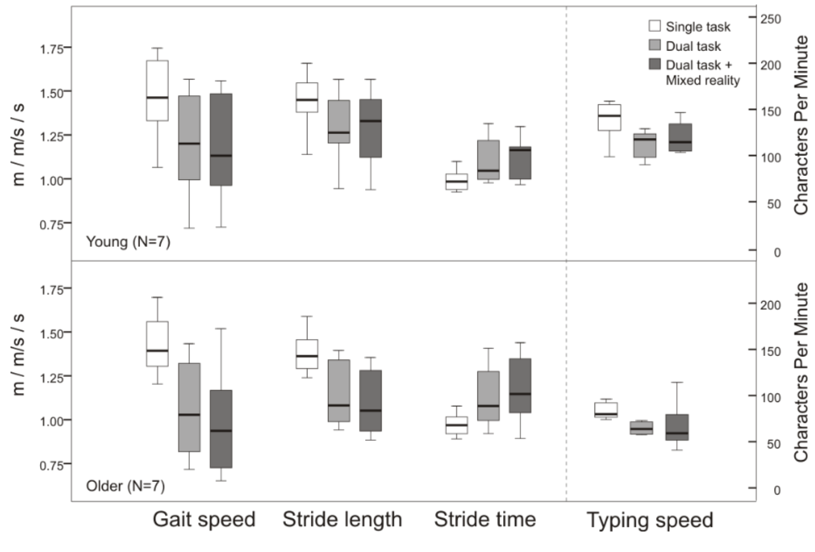

Figure 3. *Gait spatiotemporal parameters and text typing speed for young (top panel) and older adults under three conditions: Single task (walking/texting only), dual task (walking and texting) and dual task with mixed reality (walking and texting with mixed reality display).*

Table 1. *Participants' characteristics and performance on clinical tests.*

	Young (N=7)	**Older (N=7)**
Gender	4F/3M	4F/3M
Age (Years)	26.4±4.5	69.9±3.9
Height (cm)	164.4±8.2	164.4±9.0
Dominance (Left/Right hand)	2L/5R	2L/5R
Current phone's operating system	7 Android	6 Android / I iOS
Time with current phone (months)	16.0±15.7	6.6±3.5
Texts per day (% of subjects)		
Under 10	28.6	71.4
10-30	28.6	28.6
31-50	28.6	
51-70	14.3	
Use phone while walking (% of subjects)		
Not at all	14.3	42.9
>25% of walk time	42.9	57.1
25%-50% of walk time	14.3	
50%-75% of walk time	14.3	
>75% of walk time	14.3	
Ever stumbled/fell while using phone		
No	71.4	100
Yes	28.6	-
If yes, how often		
Rarely	-	-
Occasionally	100	-
Often	-	-
TUG	6.57±1.03	7.43±0.76
TUG-cognitive	7.37±1.60	7.42±0.77
MoCA	--	24.14±3.02
TMTa	27.95±6.03	38.41±10.83
TMTb	72.82±22.38	82.94±37.35
Maximum typing speed	295.13±6.16	299.47±5.48

3.5 Subjective experience

Young adults found the mixed reality presentation to be moderately helpful with a VAS 1 median score of 28.32 (IQR=19.47-84.07). Older adults, however, reported that they did not find the mixed reality helpful with a VAS 1 median score of 4.42 (IQR=0.0-13.27). The difference between the groups was significant (U=3, p=.006).

With regard to the likelihood of using an MR app in the future, the older adults reported a median VAS 2 score of 7.96 (IQR=0.0-11.50) while the young adults reported a median VAS 2 score of 27.43 (IQR=9.73-71.68). The difference between the groups was significant (U=8, p=.04).

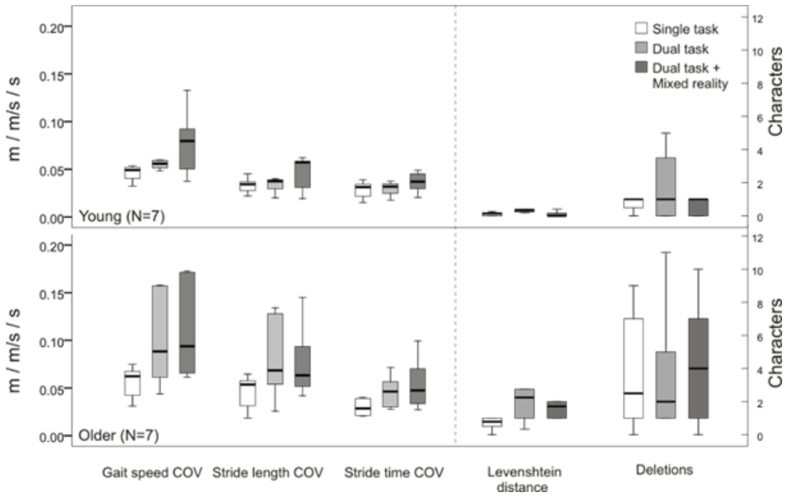

Figure 4. *Covariance of gait spatiotemporal parameters (left) and additional texting parameters (accuracy-Levenshtein distance and number of deletions) for young (top panel) and older adults under three conditions: Single task (walking/texting only), dual task (walking and texting) and dual task with mixed reality (walking and texting with mixed reality display).*

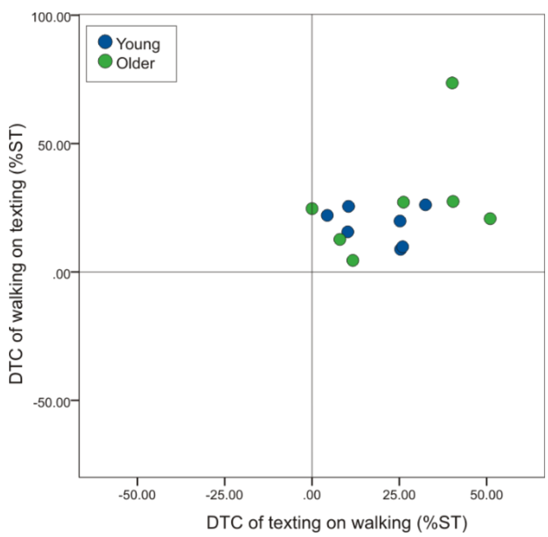

Figure 5. *Dual Task Cost (DTC) of texting on walking (gait speed) vs. DTC of walking on texting (typing speed) for young (green) and older (blue)subjects. Positive values of DTCs indicate a dual-task interference effect.*

4. CONCLUSIONS

These initial results showed that texting while walking generated similar patterns of decrements in the performance of walking while texting tasks in both young and older adults. According to Plummer and Eskes (2015), a complete measurement of dual task interference needs to include the cost of each task on the performance of the other. In the current study, no facilitation of either task was noted for either young or older adults, nor did there appear to be a trade-off between the two tasks. Rather, dual task performance resulted in interference for both texting and walking (Figure 5). These findings extend the results from existing studies, which only described decrements in gait performance while texting in young adults (Lim et al., 2015; Lopresti-Goodman et al., 2012; Parr, Hass, & Tillman, 2014; Plummer et al., 2015; Schwebel et al., 2012).

Differences between the groups in all conditions were found only in the texting task. This may be due to the familiarity and experience of the younger adults with texting with and without walking, as was indicated by their self-reports. A larger sample of older adults may permit discrimination between different levels of familiarity with the task in this population as well. The lack of differences between the groups in the other parameters as well as in the DTC may be explained by the relatively quiet walking environment that did not impose challenges to the high-functioning (community dwelling) older adults who participated in this study. In addition, the small sample size may have prevented some of the differences from reaching statistical significance.

The initial findings reported in the current paper support the feasibility of the protocol for studying the dual-task cost of texting while walking, and especially the contribution of MR to the ability to perform this type of dual-task. The similar patterns of performance that were observed in older and younger adults (e.g. lack of differences in gait and typing speed between the DT and MR conditions within both groups) further support the feasibility of the protocol. From these initial results it seems that MR did not affect performance of texting while walking. However, younger adults reported that it was more helpful to them and that they will be more likely to use it in the future. This may reflect generational differences in adopting new technologies during routine daily activities, and may have implications for the design of mobile phone applications for older adults in the future, e.g. larger texts or higher contrast to accommodate older users (Holzinger, Searle, & Nischelwitzer, 2007). The ability of older adults to modify performance under these dual-task conditions over time should also be investigated using a motor learning paradigm.

Acknowledgements: Yaniv Dubowski, Reut Binyamin and Keren Tzitiad for their help with data collection and Noam Dahan for his help with development of the mobile app. The study was funded by University of Haifa Institutional Postdoctoral Fellowship Program and the Israel Center of Research Excellence: Learning in a NetworKed Society.

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Designing a location-aware augmented and alternative communication system to support people with language and speech disorders

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ABSTRACT

Working with those who have speech and language disorders can be a great challenge for researchers. Language difficulties can significantly affect a user's ability to communicate with others. Our aim is to design an Augmentative and Alternative Communication (AAC) system based on current location for people with language disorders in order to support communication in their everyday life. In this paper, we design a location based AAC system that provides a list of images that is able to assist in communication.

1. INTRODUCTION

Speech and language impairment is defined as a communication disorder that adversely affects not only a child's but also an adult's ability to talk, understand, read, and write. Augmentative and alternative communication (AAC) methods include all forms of communication (other than oral speech) that are used to express thoughts, needs, wants, and ideas. AAC devices can range from a simple picture board to a computer program that synthesizes speech from text. Generally, AAC systems are used when facial expressions or gestures are made to communicate with others using symbols or pictures. People with severe speech or language problems rely on AAC to supplement existing speech or to replace non-functional speech. Special augmentative aids, such as picture and symbol communication boards and electronic devices, are available to help people express themselves. These can help to increase social interaction, school performance, and feelings of self-worth. AAC users should not stop using speech if they are able to do so. The AAC aids and devices that are used are meant to enhance their communication. AAC users encounter difficulty communicating via speech due to congenital and/or acquired disabilities occurring at any time across their lifespan. These conditions include but are not limited to autism, cerebral palsy, dual sensory impairments, genetic syndromes, intellectual disability, multiple disabilities, hearing impairment, disease, stroke, and head injury like aphasia.

AAC systems may help their users to communicate by providing audio or visual prompts to support the user in speaking a word or phrase, or by speaking the word or phrase via synthesized speech (Beukelman et al. 2006). Many electronic AAC systems permit a user to pre-define words and phrases that would be difficult for the user to produce instantly.

Usually, electronic AAC systems have a high initial setup cost because of the specialized hardware or software required. However, the growing ubiquity of recent mobile devices and applications has led to widespread adoption of AAC software on typical mobile devices, tablets, and PCs (Vance et al. 2009). Typical smart phone hardware often has capabilities beyond traditional AAC hardware, such as network connectivity and embedded sensors.

The capabilities of modern mobile devices provide an opportunity to improve the usability of AAC through context-aware computing (Schilit et al. 1994). Current AAC solutions often expect the user to navigate through a hierarchical menu of speech and image options in order to speak or select an image. A networked, sensor-enabled AAC mobile device may be able to identify the user's current location, task, or conversational partner, and highlight conversational options that are most relevant to the user's context. This could take the form of ordering lunch when the user is in a restaurant or discussing tennis with a sports fan. In this paper, we describe the design and development of a location based Android application for communication.

2. RELATED WORKS

Technology is often used to manage language disorders. Modern mobile devices such as smartphones have various types of applications that can be used to facilitate communication, allowing users to maintain their independence and avoid social exclusion, two of the primary features that identify supportive technologies (Newell et al. 2003). McGrenere et al. (2003) evaluated prototypes of aphasia-aware software for mobile devices. Participants reported that they could not read long streams of text like those found in recipes. As a result, the authors to developed a recipe book app, which replaced ingredient text with pictures, and a planner (Moffatt et al. 2004), which annotated each calendar event with photographs of the place and people associated with the event.

AphasiaWeb is in some sense an augmentative and alternative communication (AAC) system, which guides users through a conversation using audio and visual prompts (Hannah Miller and Chris Johnson 2013). A comprehensive treatment of AAC systems is given by Beukelman and Mirenda (2005). Kane et al. (2012) describe an AAC system specific to aphasia. Their TalkAbout system runs on a mobile device and provides context-aware prompting. For example, in a cafe the device’s screen will automatically present the user with words related to ordering coffee. This system provides audio and visual cues that guide the user through a conversation.

Daemen et al. (2007) describe a system for telling stories through pictures, sounds, emotion icons, and written annotations. Each participant in the study responded differently to the software, revealing the difficulty intrinsic to designing a comprehensive system to manage aphasia. For example, one participant valued sound as the most important input method, while another favored pictures.

Many other mobile AAC systems have been developed by Waller et al. (1998), Allen et al. (2007), Ahlsen et al. (1998), Van Dijk et al. (2010) and Keskinen et al. (2012). The main contribution of our research paper is to present a system that helps those with language disorders in an easy-to-use way. Our application supports various types of users, such as those dealing with aphasia or autism and children. The desired result is that participants can easily communicate with other conversational partner through our application.

3. METHODOLOGY

3.1 System architecture

In essence, our system contains various categories of images. We combine some other important services to further communication, such as Text to speech Service (TTS), a Database, Global Positioning System (GPS) and Internet access.

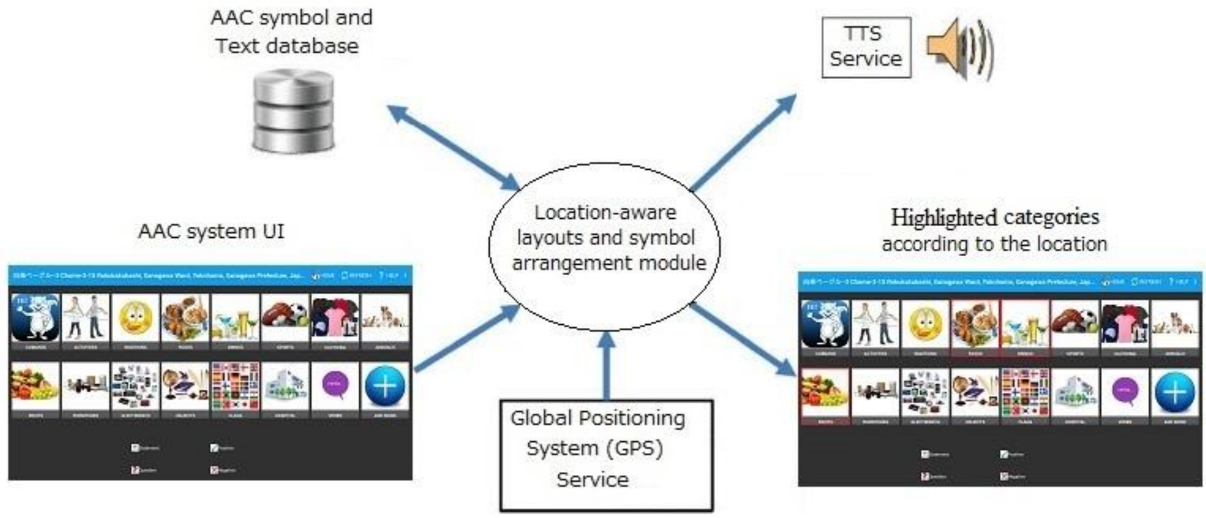

Figure 1. *Architecture of the proposed Location-aware AAC system.*

First, this system searches through the available categories based on the current location given by the GPS. Each category contains some symbols which are stored in the smartphone database. Then, the categories that are found near the current location are highlighted. A text to speech (TTS) service is an important part of any AAC system. Most current smartphones include this service. Thus, our proposed system also uses the TTS service to provide audio of the stored symbol. The overall system architecture is shown in Figure 1.

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3.2 Hardware and software

The proposed system is developed on the latest Android based tablet device. However, the application can also be installed on Android based smartphone which have API level 8 or greater. Our prototype was tested on Sony z4 tablet. This Android application was developed in Eclipse IDE; the application logic was written in Java. User data such as images and phrases were stored in the smartphone memory. We used the Google Location API and Google Place API to identify the location of the user. Finally, we use the default system Gmail client to send messages to other users.

3.3 User interface design

The purpose of our system is to provide users the ability to store, organize, browse, and speak stored words and phrases in addition to sending messages based on the images. The current prototype enables users to browse items, add new items, and filter items based on the current location.

- *Browsing items*: Each item in our system contains a picture and an associated word or phrase. The application is also capable of playing audio associated with the text using the built-in speech synthesizer. The context bar displays the current user location. Like other AAC systems, words and phrases may be assigned to hierarchical groups, which enable users to organize words and phrases by the location that they are spoken in or by the partner that they are most often discussed with.
- *Adding new items*: This process is similar to how users add content to existing AAC systems. Users may add new words or phrases to the system catalogue themselves. Adding a new item requires the user to: 1) input the text to be spoken; and 2) add an associated image. Words and phrases may be entered using the smart phone keyboard. The associated image may be captured by the user via the phone camera, selected from a set of previously captured images, or chosen automatically.
- *Filtering and updating items*: The image categories are highlighted depending on the current location. The user is capable of updating the previously stored words or phrases.

This system provides the ability to detect the user's current location via GPS. It detects the user's location using the Google Location API, which relies upon GPS and Wi-Fi localization.

3.4 Flow diagram of the system

The basic flow diagram of our system is shown in Figure 2. The system algorithm is shown in Algorithm 1 and Algorithm 2. Algorithm 1 contains the main method locationAwareAAC() and Algorithm 2 contains the supporting method getCurrentLocation() for the main method. The method locationAwareAAC() calls the method getCurrentLocation() to get the current location information using the Google Location API and Google Place API.

Algorithm 1:

locationAwareAAC()

1. Get current location using getCurrentLocation()
2. resultCategories = Query the database and get the category list using the current location.
3. If (resultCategories !=NULL) then load and highlight the categories. Otherwise no need to highlight and load categories.
4. Select any category.
5. Select any item to hear a full sentence using TTS.
6. If the user wants to send an email then send the text associated with the image to the partner. When the user sends the image it will automatically attach the current address.

Algorithm 2:

getCurrentLocation ()

1. Check the internet connection
2. Find the current location using the Google Location API and Google Place API.
3. Return location.

3.5 Detecting location

One of the unique features of mobile applications is location awareness. Mobile users take their devices with them everywhere; adding location awareness to our app offers users a more contextual experience. The location

APIs available from Google Play services facilitate the addition of location awareness to our application with automated location tracking. To detect the current location we use the Google Location API. First, we need to check if internet is available to the device. If internet connection is available then we find the current location using the Google Place API. The Google Place API works with a specific category of word, such as food, bank, restaurant, school etc. We then apply a database query to match the current location with the stored image database. After results are found, categories that match with the current location are highlighted. Our current system checks categories within a 500m radius from the current device position.

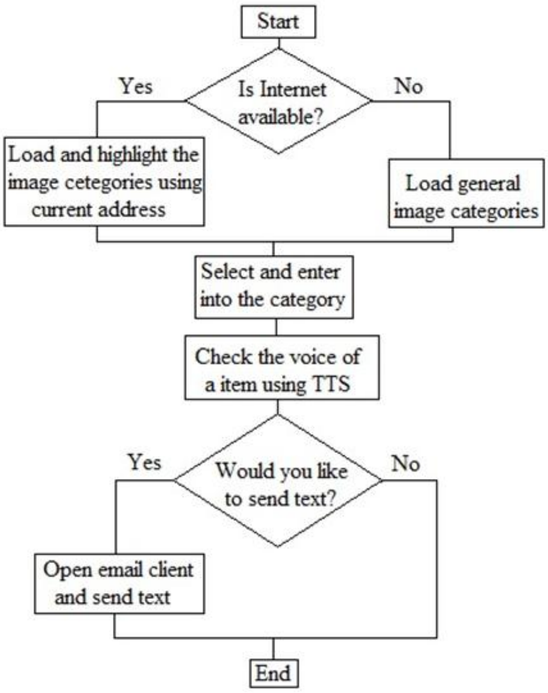


Figure 2. *Flow diagram of the proposed system.*

3.5 Text to Speech service

Our system was developed on an Android OS (Version 6.0 Marshmallow) and allows us to convert text into voice. It allows us not only to convert image into text but also to speak the text in a variety of different languages. Java provides the TextToSpeech class for this purpose. After choosing specific category, we can choose an image, at which point the application gives the word or full sentence that is stored in the image database.

3.6 Sending email

To send an email from our application, we are able to use the existing default email client provided by the smartphone OS such as Gmail, Outlook, K-9 Mail etc. To do this, it was necessary to write an Activity that launches an email client, using an implicit Intent with the correct action and data. After choosing an image from a category, the system sends the text associated with those images using our device's default email client. When a healthy user receives email, they are unaware if the sender has a disability or not. In this way, our system can improve empathy for the affected people.

4. RESULT AND DISCUSSION

4.1 User community

This application is designed as a single user system to be used in everyday life for an individual with limited or no speech capabilities. We constructed the application with four distinct user communities in mind.

- *Aphasia user*: This community can understand everything but have lost their ability to speak and possibly read. Therefore, they will need icons to identify words and a high-level vocabulary.
- *Autism user*: These users are characterized by a difficulty in communicating and forming relationships with other people and in using language and abstract concepts.

- *Children*: If children wish to communicate with others when they are incapable of writing a sentence, this system can help them use images and voice to create a sentence.
- *Foreign language speakers*: This system not only supports the English but also other languages. Thus, users are able to easily operate, generate, and use the local language with this system.

4.2 Usability testing

Usability testing is a method of testing a product while considering the target users in order to find usability problems existing in the product. A usability study aids in the removal of design issues, which should improve the end user experience with the product. In usability testing, users are given tasks to perform using the product and observed to see if they have any problems performing the tasks. While the user is performing the task, the usability team will observe how the user is navigating the application as well as the user facial expression to observe how they are reacting to the application. Depending on the observations, the usability team will suggest design solutions. Real users should be utilized in usability testing because they don't know the internal details of the system. Thus, we test our system on Japanese students in an English environment. After using our system they rated it on a 5 point scale (1=low, 5=high). The result of their rating is shown in Table 1.

Table 1. *Usability testing result.*

Participant	Age	Liked application	Better than current	Would use
P1	23	5	5	5
P2	23	4	5	5
P3	24	3	4	4
P4	23	5	5	4
P5	25	4	5	5

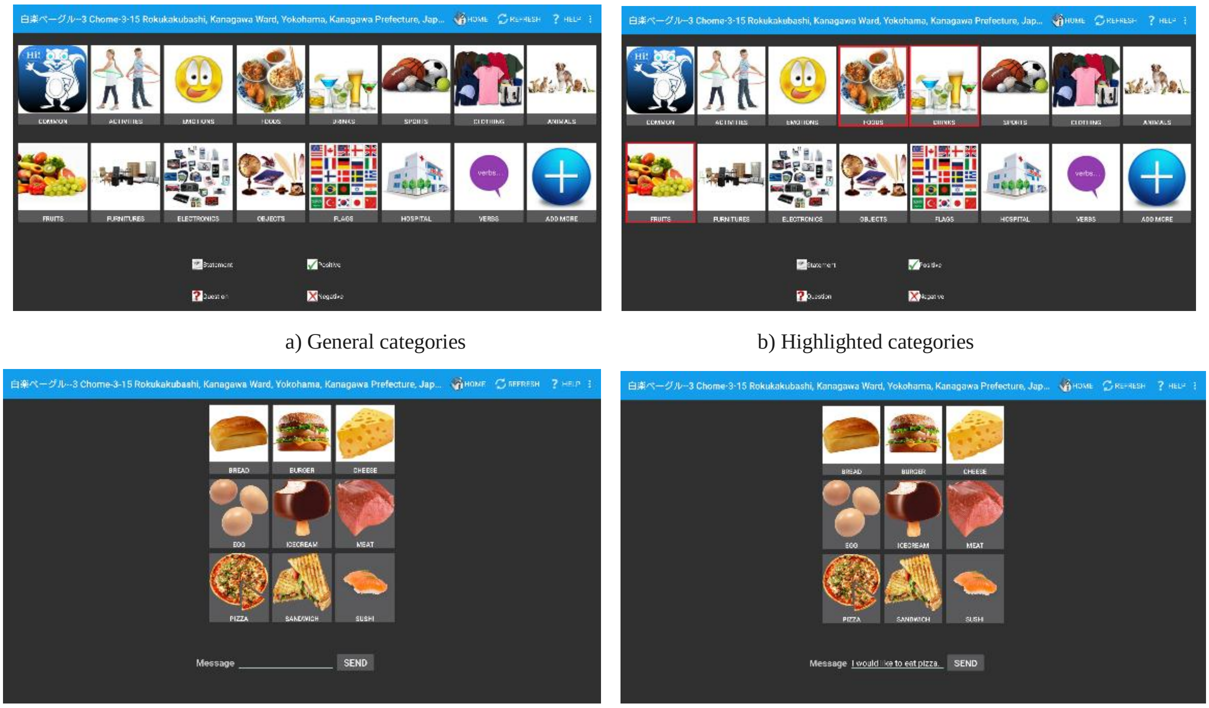
4.3 Discussion of result

The operation of our system is very simple, as shown in Figure 3. Figure 3 (a) and (b) show the general categories and highlighted categories. If a restaurant, café or supermarket is near the current location then the system will automatically highlight the food, drink and fruit categories. The last two images (c) and (d) of Figure 3 show the application after selecting the food category. Figure 3 (d) shows the message in the message box after confirming an item in the category. Finally, it is possible to send a message via email with the current location by pressing the send button.

This paper demonstrates some communication methods that help individuals who struggle to produce or comprehend spoken or written language. The developed system provides mobile based language therapy that can lead to positive changes in the language and functional communication skills of individuals with speech and language disorders. This system can easily capture and manage photographs using a mobile device, which is useful to people with such a disability. Users may find different applications for the system that are influenced not only by the nature of their diseases but also by their personal circumstances and communicative goals. For example, individuals with autism think in a visual way and recall visual images and memories easily. They can understand and benefit from concrete and visual information regarding daily events. Our system can present language in a consistent and visual manner. Children with autism, cerebral palsy, developmental disabilities, or rare genetic syndromes can receive communication and learning support through our system. We also believe our system can assist those who cannot speak foreign languages but start to live in a foreign country. This system provides support for different types of users who have Android based smartphones. AphasiaWeb is a web application that provides only visual and audio prompts for an aphasia user. It is a social networking web application where users can share their thoughts and feelings. Similarly, TalkAbout and PhotoTalk support only people with aphasia. However our system is able to assist multiple user communities. It also supports multiple languages. It can help users send their generated messages to other users similar to an instant messaging system. The proposed system uses mobile device GPS that can give the application the current user location. This system has a rich image library that can properly support the user. Moreover, actual AAC systems are expensive and specialized. However, our system is implemented on an Android operating system, which is popular all over the world. When reading the email messages, it is not possible to notice that the users have language impairment. Thus, they are treated as a normal user. As a result, our system automatically increases empathy towards the user. Table 2 shows a comparison to other systems.

Table 2. *Comparison with other systems.*

Name	Platform	Type	Users
AphasiaWeb	Web	AAC for Social Networking	Aphasia
TalkAbout	iOS	AAC only	Aphasia
PhotoTalk	iPAQ pocket pc (windows)	AAC Only	Aphasia
Proposed system	Android	Instant messaging with AAC	Aphasia, autism, children, people with other languages



a) General categories b) Highlighted categories

c) Category of Foods d) Message box with message after selecting the item pizza

Figure 3. *Screenshot of the proposed system.*

5. CONCLUSION

We have implemented an AAC system for people with speech disabilities. Most people with speech disabilities currently use AAC devices and mobile applications. At this time, available applications are more cost effective but less user-friendly and have limited vocabularies which are geared toward users with limited cognitive abilities and only available in English. In contrast, our system is user-friendly, contains a large vocabulary, target users with higher cognitive abilities, supports multi-language use and location-awareness, and is extremely inexpensive. Finally, the first prototype was built on the latest Android OS because it has the largest user community all over the world. In addition, we have checked our system with occupational therapists. During the testing session, we received some suggestions. In the future, we intend to include theirs suggestions in our system so that we can better support the individuals with language and speech related disabilities.

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Comparison of functional benefits of self-management training for amputees under virtual world and e-learning conditions

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ABSTRACT

Amputation is a life-long condition. Throughout their lifespan, amputees will need health, wellness and prosthetic-related information. This project used a randomized design to compare two methods of disseminating an evidence-based self-management intervention: avatar-based virtual world and e-learning environments. Of the 57 subjects randomized, 37 (65%) completed the study. The virtual world group had a significantly higher drop-out rate than the e-learning group. Both groups marginally improved on self-efficacy, perceived social support, pain interference, and functional status outcomes with no significant results found between the groups.

1. INTRODUCTION

Nearly 2 million people live with limb loss in the United States of America (ACA, 2012; K. Ziegler-Graham, E. J. MacKenzie, P. L. Ephraim, T. G. Travison, & R. Brookmeyer, 2008), with projections to reach 3.6 million persons by 2050 (K. Ziegler-Graham, E.J. Mackenzie, P.L. Ephraim, T.G. Travison, & R. Brookmeyer, 2008). Approximately 185,000 amputations occur in the U.S. each year (ACA, 2012; CDC, 1998). However, amputation is not only a U.S. issue, but a global one. For example, in countries such as Angola and Cambodia where land mines are the cause of most traumatic amputations, there are more than 50 amputees per 20,000 people (“Landmines: the facts,” 1997). While global amputee prevalence rates are not available, the World Health Organization estimates that more than 30 million people in Africa, Asia, and Latin America combined are in need of prosthetic and other assistive devices (WHO, 2004).

Since amputation is a life-long condition, it is important for those with limb loss to be educated consumers of information about current and evolving medical procedures, prosthetic technologies, rehabilitative interventions, and health and wellness. Prosthetic devices must be provided throughout the lifespan of individuals with amputation. For example, prosthetic devices provided in the US by the Department of Defense or the Department of Veterans Affairs are typically replaced in less than two years (McFarland et al., 2009). Selecting appropriate prosthetic components can be overwhelming because of emerging technology. In fact, amputees have reported a lack of available information on new prosthetic devices (Berke et al., 2010). Prevention and treatment of secondary health conditions associated with amputation and prosthetic device use are also needed throughout the lifespan of individuals with amputation, for conditions such as pain (Ehde et al., 2000), skin problems (Bui, Raugi, Nguyen, & Reiber, 2009; Meulenbelt, Geertzen, Dijkstra, & Jonkman, 2007; Reiber et al., 2010), heterotopic ossification (Berke et al., 2010), arthritis (Norvell et al., 2005; Reiber et al., 2010), cumulative trauma disorders and overuse injuries of the non-involved limb (McFarland et al., 2009), and psychological/mental health issues (Horgan & MacLachlan, 2004; Ostlie, Magnus, Skjeldal, Garfelt, & Tambs, 2011). Individuals with limb loss who feel they are well educated about their amputation care are more likely to adhere to treatment recommendations and have improved health outcomes (Berke et al., 2010).

Self-management interjects active participation into treatment (Creer, Renne, & Christian, 1976). The effectiveness of self-management programs is attributed not to changes in behaviour, but rather to enhanced self-efficacy or a feeling of control over the illness/disability (Bandura, 1977a; Lorig & Holman, 2003). Programs that teach self-efficacy are more effective in improving clinical outcomes than traditional patient education (Bodenheimer, Lorig, Holman, & Grumbach, 2002).

The problem that this research addresses is providing access to this self-management education, especially for amputees with mobility and/or geographic barriers. This training was initially designed to assist with community integration for service members with combat-related amputations who had been discharged from specialized rehabilitation and were returning home. The training was extended to non-service member amputees. Guided by Bandura's theoretical model, this project created a virtual world environment in Second Life® (SL; www.secondlife.com), thus expanding interactive dissemination of health and prosthetic-related evidence-based information from face-to-face (clinician to patient) to the Internet (virtual world). A virtual world environment removes travel and accessibility barriers that are particularly challenging for individuals in rural areas and individuals with disabilities (Chan, Hart, & Goodman, 2006; Guagliardo, 2004) and hosts a global audience. The research question asked if being able to observe yourself immersed, as an avatar, in performing balance and conditioning exercises, for example, added value to the training compared to watching video of peers performing the tasks.

2. METHODS

Institutional Review Board (IRB) approval was received from Nova Southeastern University and the Miami Veterans Affairs Healthcare System IRB and Research and Development Committee.

2.1 Design

This study had a development and an experimental phase. During the development phase, subject experts created the content of the self-management training based on Alberto Esquenazi's Stages of Rehabilitation for Amputees (Esquenazi, 2004). Using Microsoft PowerPoint as the authoring tool, a visual presentation with accompanying video and still graphics was created and then used by the virtual world and e-learning developers to build the experimental and control conditions, respectively. Content was beta-tested; results have been reported previously (Winkler et al., 2016). The two research environments—virtual world (VW) using SL and e-learning (EL) using Articulate® software (www.articulate.com) - were created based on identical PowerPoint content (see Figure 1).

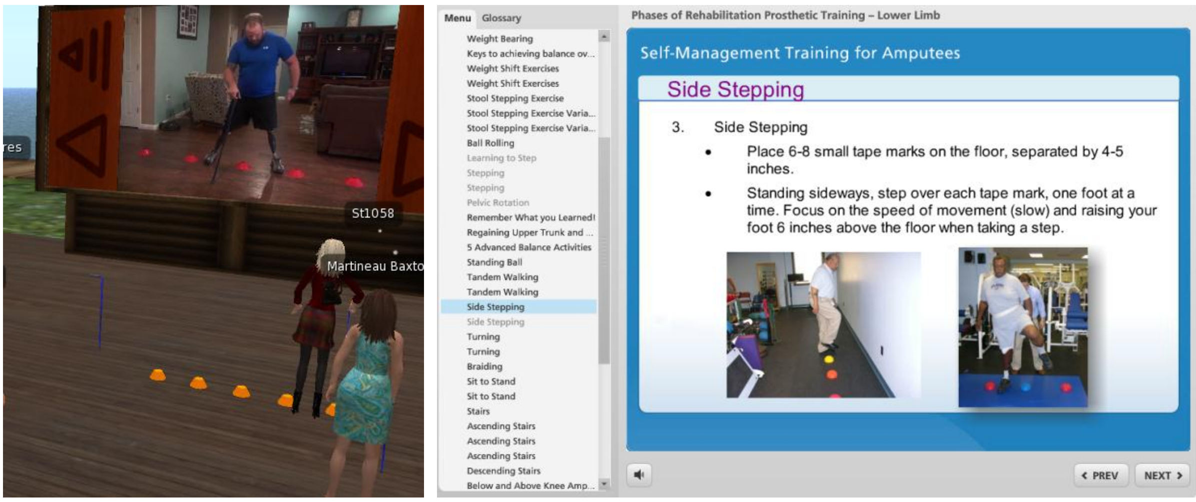

Figure 1. *A side-stepping balance exercise in the virtual world condition (left) and the e-learning condition (right).*

2.2 Subjects and Recruitment

The experimental phase used a randomized, pre- and post-design to compare the effectiveness of the intervention under two conditions: virtual world and e-learning. The results of the experimental phase are reported in this paper.

Amputee subjects were recruited to participate via IRB-approved flyers with a targeted enrolment of 92. The majority of subjects were recruited from advertisement of the study on the Amputee Coalition website. Inclusion criteria included: major amputation; access to a computer; functional use of computer (mouse, voice activation software); English-speaking. The only exclusion criterion was finger or toe amputation(s) only. Subjects did not need to be using prostheses to be included in the study. See **Table 1** for a comparison of subjects randomized to the experimental and control groups as well as a comparison of those completing the study.

2.3 Theoretical Approach

This project was guided by Bandura's self-efficacy theory (Bandura, 1977b), addressing each of the four sources of self-efficacy: (1) Performance accomplishment/mastery, (2) Modeling/vicarious experience, (3) Verbal persuasion/Interpretation of symptoms, and (4) Social persuasion (Bandura, 1977a; Lorig & Holman, 2003). The project was also guided by Kraiger's theory of training evaluation (Kraiger, Ford, & Salas, 1993) that expands learning outcomes to include cognitive (knowledge, metacognition), skill-based (skill development, ability to apply learned behaviours to new task settings), and affective (self-efficacy) outcomes, all of which are represented in the self-management intervention.

2.4 Procedure

After signing the informed consent document, subjects provided baseline demographic information, including protected health information, over the phone. Baseline outcomes data were completed electronically using REDCap, an electronic data capture system (Harris, 2009) hosted at Nova Southeastern University; thus, the investigators were blinded to outcomes data collection. Subjects were then randomized and oriented to either the VW or EL trainings.

Subjects randomized to the EL group received an email with the link to the Articulate® software training. The e-learning presentation content (text and videos) was identical to the virtual world content. The difference was the modality of content delivery. For the EL training, amputees worked alone on their own computer, navigating through the content by menu selections. Only two subjects randomized to the EL training needed assistance, which consisted of instruction to click on the arrow icon to advance the slides.

Subjects randomized to the VW group were oriented by providing them with a manual (by research staff approved by the IRB to have subject contact) that explained how to get a free SL account and avatar, how to log into SL, and the SL location where they would meet a buddy who would train them in SL and how to operate their avatar. Once the subject had an avatar, a the same research staff member met them in SL and introduced them to their "buddy" who provided further training in basic avatar navigation and communication, the subjects were granted access to the research island. This hand off from research staff to "buddy" was important because only the research staff knew the subjects real identity. Once the subject had an avatar, they could be anonymous, as the "buddy" was not authorized by the IRB to have access to protected health information.

The research island had 17 stations with content including the history of prosthetics, the epidemiology of amputation, building prosthetic devices, conditioning and balance exercises, activities of daily living tasks, social emotional adjustment, and community reintegration. The experimental group walked their avatar through the 17 stations, with opportunities to wear virtual prosthetics and participate in virtual simulations, e.g., watching their avatar walk up and down stairs as a bilateral lower limb amputee, and to move through the stations with other amputees (avatars).

Subjects completed the trainings at their own pace. When finished, subjects completed the electronic outcomes assessment, using REDCap, for a second time.

2.5 Outcomes

The outcomes were self-efficacy, perceived social support, pain interference, and upper level and lower level limb function.

2.5.1 Self-efficacy was measured using two scales: the General Self-Efficacy Scale (GSE) and the Stanford University School of Medicine Patient Education Chronic Disease Self-Efficacy Scale (Lorig, Stewart, & Ritter, 1996) . The 10-item GSE scale assesses a general sense of perceived self-efficacy to predict coping with daily hassles as well as adaptation after experiencing all kinds of stressful life events. The GSE has 10 items with a scale of 1 to 4 each and a possible total mean range from 1-4, with a higher score indicating greater self-efficacy. Six of the 10 Stanford scale items were used. The items each have a scale of 0 to 10 for a possible total mean range from 0-10, with a higher score indicating greater self-efficacy.

2.5.2 Perceived social support was measured using the Multidimensional Scale of Perceived Social Support (MSPSS) (Zimet, Powell, Farley, Werkman, & Berkoff, 1990). The MSPSS measures the perceived availability of support. The MSPSS has 12 items each with a Likert-type scale of 1 to 7 for a possible total mean range from 1-7; a higher score indicates greater perceived social support.

2.5.3 Pain Interference was measured using the "Pain Interference" component of the West Haven-Yale Multidimensional Pain Inventory (WHYMPI) (Kerns, Turk, & Rudy, 1985). The WHYMPI is a 52-item, 12-scale inventory that is divided into three parts. Part I includes five scales designed to measure important dimensions of the chronic pain experience including: 1) perceived interference of pain in vocational, social/recreational, and family/marital functioning; 2) support or concern from spouse or significant other; 3) pain severity; 4) perceived life control; and 5) affective distress. Part II assesses patients' perceptions of the degree to which spouses or significant others display Solicitous, Distracting or Negative responses to their pain behaviours and complaints. Part III assesses patients' report of the frequency with which they engage in four categories of common everyday activities; Household Chores, Outdoor Work, Activities Away from Home, and Social Activities. Only the nine items assessing the interference pain has on subjects' lives and their levels of affective distress were used in this study. The nine WHYMPI items each have a Likert-type scale of 0 to 6 for a possible total mean range from 0-6; a higher score indicates greater pain interference.

2.5.4 Functional Status was measured using the Orthotics Prosthetics User's Survey (OPUS) (Burger, Franchignoni, Heinemann, Kotnik, & Giordano, 2008; Heinemann, Bode, & O'Reilly, 2003; Jarl, Heinemann, & Norling Hermansson, 2012). The Orthotics and Prosthetics Users' Survey (OPUS) is a patient-reported outcome measure consisting of five modules assessing Lower Extremity Functional Status (LEFS), Upper Extremity Functional Status (UEFS), Client Satisfaction with Device, Client Satisfaction with Services, and, Health-Related Quality of Life. Only the LEFS and/or UEFS modules (whichever were appropriate for the subject) were used in this study. The LEFS has 20 items each with a Likert-type scale of 1 to 5 for a possible mean range from 1-5; a higher score indicates better function. The UEFS has 28 items each with a Likert-type scale of 1 to 5 for a possible mean range from 1-5; a higher score indicates better function.

2.6 Statistical Methods

Descriptive statistics of the sample for both randomized subjects and study completers by group include race, gender, amputation type, time since amputation, etiology, prosthetic use frequency, and computer usage. Frequencies for categorical variables and means (standard deviation) for continuous variables are presented. For outcome measures, baseline outcomes were subtracted from post-treatment scores in order to create change scores. Change scores for the two groups were tested using two-sided Wilcoxon rank sum tests. A significance level of 0.05 was used for all tests.

3. RESULTS

Of the 59 subjects enrolled, 57 were randomized: 28 to the VW experimental group and 29 to the EL control group. Of the 57 subjects randomized, 37 (65%) completed the study. The VW group had a significantly higher drop-out rate; 14/28 (50%) of the VW group dropped out while 6/29 (21%) of the EL group dropped out ($p=0.02$).

Table 1 compares characteristics of the VW (experimental) and EL (control) groups. While the dropout rate was high for the study (35% overall), measurable demographic differences were not found between study completers and dropouts, with only a trend towards newer amputees being more likely to complete the study. Randomization groups were comparable both overall and when comparing only completers.

Table 2 displays the change in self-efficacy, perceived social support, pain interference, and upper and lower limb functioning for the control and experimental groups. Both groups descriptively benefited from the self-management training, with small increases observed in self-efficacy, increases in social support, decreases in pain interference, and increases in lower limb function. While the VW group showed slightly better improvements, when using two-sided Wilcoxon rank sum tests to compare the groups on change scores, no statistically significant differences were observed.

Table 1. *Description of sample.*

		Total Randomized (n=57)		Study Completers (n=37)	
		VW n=28	EL n=29	VW n=14	EL n=23
Age: mean (sd)		48.7 (14.4)	51.8 (14.9)	50.6 (12.4)	48.4 (13.9)
Race/ethnicity	White	22 (79)	25 (86)	13 (93)	20 (87)
n (%)	Black	4 (14)	1 (3)	1 (7)	1 (4)
	Other	2 (7)	3 (10)	0 (0)	2 (9)
Gender	Male	18 (64)	18 (62)	11 (79)	15 (65)
n (%)	Female	10 (36)	11 (38)	3 (21)	8 (35)
Amputation	Unilateral UL	2(7)	1 (3)	1 (7)	1 (4)
n (%)	Unilateral LL	22 (79)	21(72)	11 (79)	17 (74)
	Bilateral LL	1(4)	5 (17)	1 (7)	3 (13)
	Unilateral UL & Bilateral LL	1(4)	0(0)	1(7)	0(0)
	Unilateral UL & Bilateral LL	0 (0)	1 (3)	0 (0)	1 (4)
	Quad	2 (7)	1 (3)	0 (0)	1 (4)
Years since 1st amputation	0-5	21 (75)	16 (55)	11 (79)	14 (61)
n (%)	6-10	2 (7)	7 (24)	1 (7)	3 (13)
	11-15	1 (4)	4 (14)	1 (7)	4 (17)
	>15	4 (14)	2 (7)	1 (7)	2 (9)
Etiology	Trauma	9 (32)	12 (41)	5 (36)	11 (48)
n (%)	Dysvascular Disease	8 (29)	7 (24)	4 (29)	10 (43)
	Other Medical	11 (39)	10 (34)	5 (36)	2 (9)
Prosthetic use	Daily	23 (82)	25(86)	10 (71)	19 (83)
n (%)	Weekly	0 (0)	2 (7)	0 (0)	2 (9)
	Monthly or less	0 (0)	1 (3)	0 (0)	1 (4)
	Did not use prosthesis	5(18)	1 (3)	4 (29)	1 (4)
On computer Mean (sd)	Hours per week	29.6 (15.1)	31.2 (20.2)	28.9 (12.0)	31.8 (20.6)

Table 2. *Comparison of pre and post change in outcomes scores for the virtual world (VW) and e-learning (EL) groups.*

Outcomes	VW (n=14)					EL (n=23)					P value
	n	Pre	Post	Change	ES+	n	Pre	Post	Change	ES	
Self-efficacy (GSE)	14	3.54	3.56	0.03	0.11	23	3.48	3.49	0.01	0.05	0.97
Self-efficacy (SSE)	14	8.68	8.85	0.17	0.15	23	8.04	7.97	-0.07	-0.06	0.80
Social support	14	5.38	5.62	0.24	0.30	23	5.91	6.00	0.09	0.11	0.56
Pain interference#	9	2.05	1.85	-0.20	-0.21	19	3.28	3.10	-0.17	-0.18	0.75
Lower limb function^	11	3.34	3.44	0.10	0.37	20	3.23	3.33	0.10	0.37	0.87
Upper limb function*	2	3.13	3.00	-0.13	-0.37	3	2.75	2.86	0.11	0.31	---

+Effect Size, mean change divided by the pooled standard deviation of change scores

#Pain Interference: Lower scores indicate less interference

^Lower Limb Function: 4 subjects excluded due to data entry errors

**Upper Limb function was not tested due to small sample size (n=5)*

4. DISCUSSION

This project compared the dissemination of a self-management training for amputees under two conditions: virtual world and e-learning. The difference between the two conditions was that the subjects in the avatar-based VW group were immersed in the training, engaging in simulations of desired health activities, e.g., performing activities of daily living transfers, conditioning and balance exercises, going up and down stairs, etc. Small benefits from the self-management training were observed for both groups across the outcomes considered. However, no statistically significant differences were observed between the groups.

The original study plan called for a total enrolment of n=100 in order to achieve 92 evaluable subjects, and was powered to detect moderate effect sizes of 0.6. Unfortunately, the enrolment rate was less than expected and dropout rates were higher than expected. Additionally, the dropout rate for the VW group was significantly larger than for the EL group. Because of the lower than expected enrolment and high dropout rate (50% in the VW group and 21% in the EL group), the study was underpowered to detect a significant difference unless large effect sizes were observed. The reasons for subjects dropping out of the SL group varied. One subject believed that the SL software was a virus and took his computer to a repair shop to have it removed. Two to three two subjects (out of the 57 randomized) did not have an adequate graphic card to run SL. A couple of older subjects (aged over 80) were frustrated with the technology. Two of the three amputees with loss of all four limbs had difficulty with navigation; the third completed the study using voice recognition software. Several amputees were just too busy to complete 17 stations: these amputees were working, raising children, engaged in sports, etc. In reflection, the training was comprehensive but probably too long. Most drops outs went into the virtual world once or twice, but not the multiple times needed to complete the study. That being said, one or two subjects completed the 17 virtual world stations in one or two sessions. Only one amputee reported not feeling safe in a virtual world. Recruitment was also affected by the nature of the intervention; many amputees who inquired about the study did not enrol. Subjects reported wanting to participate in studies if it helped other amputees, but were perhaps negatively influenced about having to participate in the study as an avatar. Younger subjects who were familiar with avatars seemed to complete the intervention more easily and quickly.

There were limitations with the way that two of the outcomes measures, pain interference and function, were used in this study. Pain interference data was excluded for nine subjects because seven subjects put not applicable for all items pre/post, one put not applicable for all items post, and one had pre, but rated seven out of nine items not applicable on the post test. Future studies will include a clarifying item: I have pain, yes or no, and then ask subjects who have pain to complete the pain interference questions.

Additionally, there was confusion for the upper and lower limb functioning questionnaire that led to further data loss. Each participant has access to complete both measures, regardless of amputation type. While not applicable was a choice that many correctly used, others inadvertently filled out incorrect portions. Specifically, two participants did not complete the pre-test, one did not complete the post-test, and two other completed the pre-test for upper limb function, but not for lower limb function. Contributing to this confusion was the investigators' use of electronic data collection for the first time. Although the electronic forms were piloted before use, future studies will include more extensive pilot testing prior to implementation.

In general, the amputees most likely to complete the virtual world training were new amputees; in fact, several subjects' avatars were wearing virtual prostheses before they received their real life or non-virtual prostheses. Notably, dropouts had lower baseline pain interference (less pain interference) on average than completers (Wilcoxon two-sided p=0.024), suggesting that dropout could be related to less need for therapy. The study results suggest that the virtual world training may be most appropriate for amputees who are receiving inpatient and outpatient rehabilitation, do not have access to rehabilitation, want to connect with other amputees, and want to experience activities that they can no longer do post-amputation. In a current project, this research team is adding a self-management training for diabetics at risk for foot ulcers; participants will have an opportunity to interact with amputees who have experienced diabetes-related amputations.

5. CONCLUSIONS

Amputees in the e-learning and virtual world groups benefited somewhat from the self-management training. The results suggest that the virtual world training may be most appropriate for amputees who do not have access to rehabilitation and as an adjunct to inpatient and outpatient rehabilitation, especially for amputees who want to connect with other amputees or experience activities that they can no longer do post-amputation(s).

Acknowledgements: We would like to thank all the individuals with limb differences who participated in this project. This project is supported by the Agency for Healthcare Research and Quality Award # R24HS022021, PI Sandra Winkler, 2013-2017.

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Choosing virtual and augmented reality hardware for virtual rehabilitation: process and considerations

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ABSTRACT

Virtual and Augmented Reality hardware has become much more affordable in the past three years, largely due to the availability of affordable sensors and smartphone displays as well as financial investments and buy-in through the entertainment industry. Many new consumer devices are becoming available to researchers, clinicians and software developers. With so many options available, planning a Virtual Rehabilitation project and selecting appropriate hardware components can be a challenge. This paper presents a stepwise selection process for Virtual and Augmented Reality hardware. The process is described through an example project and clinical and technical implications of each hardware choice are discussed.

1. INTRODUCTION

Recent advances in Virtual Reality (VR) and Augmented Reality (AR) technology have provided a tremendous boost to the field of Virtual Rehabilitation. There have been two main drivers that have contributed to the recent surge in VR/AR popularity and increased awareness in these technologies: availability of affordable VR/AR hardware and availability of software development tools. Both of these factors also have a large impact on Virtual Rehabilitation applications.

1.1 Availability of affordable VR/AR hardware

Largely driven by the entertainment industry, prices for VR/AR head-mounted displays (HMDs) and tracking devices have become more affordable and accessible for consumers. Instead of spending tens of thousands of dollars for sophisticated HMDs and motion platforms, researchers, clinicians and educators can now purchase immersive VR/AR systems for under USD2000. Tracking solutions such as motion platforms, head-, hand- and body-tracking as well as a wide range of display methods have become available since the first Oculus Rift Prototype was released in March 2013 (Oculus, 2012).

1.2 Availability of software development tools

Game and simulation engines are a key component for VR/AR content development. These engines give developers the tools to create interactive software applications and integrate VR/AR hardware. The trend for game and simulation engines has gone from expensive, closed systems to free access for everyone. Unity Technologies was the first company to start giving its engine away for free to individuals and small companies in 2009 (Unity Technologies, 2016). Over the past year, CryEngine (Crytek GmbH, 2016) and Unreal Engine (Epic Games, 2016) followed a similar path and are now providing free licenses to their game engines. Other companies like Amazon (Amazon Lumberyard; Amazon Web Services, 2016) are joining the market with new free game engines, giving developers even more choices for software development.

Moreover, all major game engine providers have started to work with VR/AR hardware manufacturers to seamlessly integrate HMD-support and VR/AR user input into their products. Similarly, many companies releasing VR/AR hardware have started to provide integrations and example projects for the most popular game engines. This completely negates one of the main barriers to VR/AR adoption: a lack of platform compatibility between hardware and software components (Rizzo & Kim, 2005).

As a consequence, researchers, students and hobbyists can more easily become proficient in game and simulation development and even develop applications for fully immersive VR/AR systems. Game development courses at schools, universities and online learning platforms are becoming increasingly popular. Companies and researchers wishing to join the Virtual Rehabilitation field have a growing pool of skilled developers at their disposal. Developing VR/AR systems has transitioned from an expensive, narrow field of work to a growing industry that is open for anyone to join and start developing for free.

Taken together, both driving forces have had a large impact on VR/AR in general and the Virtual Rehabilitation field specifically. Researchers, clinicians, educators and developers have more hardware and development options available to them than ever before. However, with many new products and paradigms entering the market, a lack of standards, guidelines or prior experience with choosing and applying these new technologies can negatively impact Virtual Rehabilitation projects.

This paper aims to provide guidance for selecting VR/AR hardware and software by describing a stepwise process (Fig. 1) that can be applied to Virtual Rehabilitation projects. The process includes 1. Considerations for User Groups, 2. Deployment Platforms, 3. Choice of Content Delivery and 4. Choice of User Interaction. Each step of the process will be described through an example of a Virtual Rehabilitation project. The example project is a realistic simulation of a classroom which serves as an attention training and assessment. Available VR/AR hardware options and the implications of each option on clinical use and the end user are presented. The project used in this example has been ongoing for several years, however, this paper assumes the perspective of today's VR/AR market and discusses choices that are available as of Q1 2016.

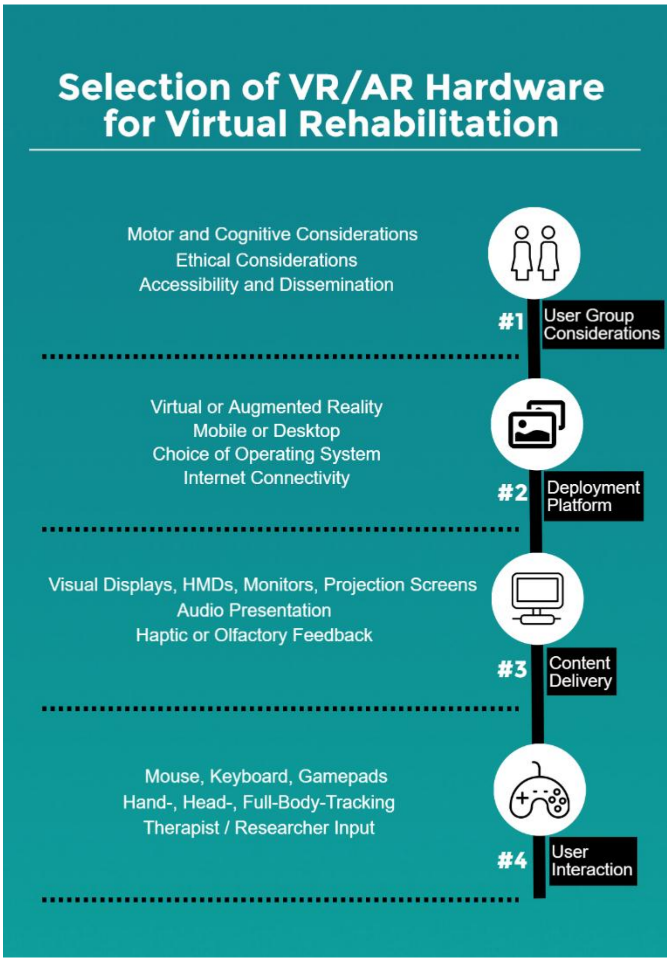

Figure 1. *Selection process for VR/AR hardware.*

These steps are presented in an order that puts steps which are more selective at the start. However, it can be necessary to re-evaluate previous steps if a desired mode of content delivery or user interaction is not supported by the chosen platform. Such cases will be mentioned in the example project.

2. DECISION PROCESS FOR SELECTING VR/AR HARDWARE FOR VIRTUAL REHABILITATION

The Virtual Classroom project (Figure 2; Klingsieck et al., 2015) aims to simulate an interactive classroom environment with students, teacher, distractions and learning content. The user is placed at a student's desk within the virtual environment and asked to monitor a task at the blackboard. Distractions are presented to challenge the user's sustained, focused and divided attention while the student has to respond to stimuli presented at the blackboard or by the teacher. The application is designed to be broadly used in research, education and clinical assessment and training. Depending on the intended use, the outlined decision process can vary considerably. The following stepwise process will focus on the training and assessment of attentional deficits in clinical use cases.

Figure 2. *Virtual Classroom scenario.*

2.1 Considerations for User Groups

Considering the needs of a user group or examining a clinical gap are fundamental steps in the planning and design of a Virtual Rehabilitation application. These considerations are essential for making any follow-up decision in steps two to four by choosing VR/AR technology that takes into account motor and cognitive deficits, accessibility and ethical principles when working with the relevant user groups.

Virtual Rehabilitation applications often are built for two user groups, patients and therapists / researchers / educators. This project targets school or university students and the therapists who are conducting the attention assessment or training. It seems reasonable to expect students to be at least familiar with computers, entertainment technology or occasionally even VR/AR hardware. Moreover, motor deficits, fatigue or other health conditions that limit the project's hardware selection seem unlikely unless comorbid conditions are expected. Ethical considerations are limited to a standard risk of simulator sickness when using immersive VR/AR systems. Consequently, no hardware or deployment options need to be ruled out based on the student user group.

No additional hardware has been excluded for this project as long as each device does not interfere with patient safety and allows the therapist / researcher / educator to directly interact with the virtual scenario in real-time. This aspect will be discussed when deciding on user interactions (step 4).

This first evaluation step ensures that projects and applications are not driven by the existence of exciting new technology, but rather with a focus on the clinical need. Eliminating hardware choices through user needs and limitations can involve very broad decisions that can be further refined in the upcoming steps. If, for example, the user group was a patient population with severe physical or cognitive limitations, and system use was limited to bedside treatment, deployment platform, content delivery and user input would be vastly different from this described example application.

2.2 Choice of Deployment Platform

This decision influences most of the remaining choices in the process, as it determines which hardware, operating system and overall complexity the project will adopt. Deployment largely depends on where the system will be used. If the aim is to use the classroom in a lab setting, a Windows desktop PC is a viable choice. If the classroom focuses on clinical usage in private practices, a mobile solution with hardware such as the Samsung GearVR (Samsung Corporation, 2016) and a smartphone seem more appropriate to provide portability and easy access. The availability of internet access in the target environment can also play a large role in choosing system components.

Most major game engines (e.g. Unity, Unreal Engine, CryEngine & Lumberyard) allow developers to deploy their software to multiple platforms without making major changes to the project. For most Virtual Rehabilitation projects and applications, the free license of CryEngine has to be excluded as a development option, as it excludes simulations and serious games. Further, CryEngine does not support deployment to mobile platforms. The remaining engines support deployment to Android, iOS and Windows, all of which seem valid choices for the Virtual Classroom project. Mac OS or Linux are not supported by most HMDs and have to be ruled out as target operating systems.

For this particular project, two additional factors play a deciding role for the deployment platform that is chosen.

Firstly, attention assessments rely on highly accurate measurements of response timings. All available deployment options should undergo additional testing to guarantee that the latency between user input, response time measurement and a reaction on the system's display is within acceptable limits.

Secondly, a simulation of over 20 animated characters requires substantial rendering capabilities. It has to be tested whether a modern smartphone can actually run an application with such complex graphics. Performance optimization and character rendering solutions are essential for deciding for or against mobile deployment, but these topics are beyond the scope of this paper.

This second decision step does provide several paths to follow for this project, but mobile and desktop deployment as well as VR and AR remain viable options. The following steps can narrow our choice of VR/AR hardware down further.

2.3 Choice of Content Delivery

Content delivery entails the presentation of visual, audio, tactile or even olfactory stimuli. Only visual and audio stimuli are relevant for this example project.

Visual stimuli presentation for the Virtual Classroom project can be achieved through monitors, HMDs or projection screens. It is essential for this project to allow the student user to freely look around the classroom. Distractions can occur in any part of the classroom and encourage the user to focus their attention on events away from the blackboard. The main goal of this application is to quantify attention and inattention. If the user looks at the blackboard and fails to respond to a relevant cue, an error is recorded. If the user is distracted and looks away from the blackboard while missing a cue, this event also captures inattention, but is a qualitatively different type of error.

Looking around the classroom can be achieved by three means: placing displays all around the user (e.g. CAVE environment), utilizing head-tracking or implementing virtual head movement. Multiple screens or CAVE environments require a complex hardware installation and are mostly prohibitive in cost and space requirements. Virtual head movement does not require actual movement by the user and is controlled via mouse, keyboard or other input devices. In light of affordable HMDs which include head-tracking, an HMD was chosen as the preferred option for head-tracking in this example project.

Mobile versus desktop deployment was already discussed in the previous section and the selection of HMD will obviously be impacted by the choice that was initially made with regard to the deployment platform. The main considerations for choosing mobile or Windows-based HMDs should be comfort, display quality, latency, integration in game engines, integrated tracking systems, price and availability of other compatible hardware such as handheld controllers. Market availability of existing HMDs may play an important role for products that have not been released as consumer versions yet and are only available as development kits. Development kits may change over time and new hardware and drivers may not be compatible with previous versions. This can negatively impact the development process and project timelines.

Comfort should be tested based on the intended maximum length of a session with the intended application. Features like padding material, total weight, weight distribution and cable-management should be considered. The weight and comfort of the newer HMDs such as the Oculus Rift or HTC Vive (HTC Corporation, 2016) was considered reasonable for use in the Virtual Classroom, because the scenarios run for no longer than one hour. Some smartphone-based HMDs require the user to hold the HMD with their hands or interact with the phone via buttons on the HMD. Such interactions were avoided for the Virtual Classroom as they interfere with the natural position of students sitting at a classroom desk.

An interesting potential option is the use of AR hardware to superimpose students, teacher and blackboard onto a real room. However, the use of this method is not suitable for a highly specific context such as the Virtual Classroom. An AR system would limit the use of the Virtual Classroom to real-world rooms that are spacious enough and contain believable furniture to support the simulation of a Virtual Classroom. In addition, the rendering of seated, fully-animated characters in unpredictable real-world spaces is a large technical challenge. Consequently, AR devices like the Microsoft HoloLens (Microsoft Corporation, 2016) and Meta2 (Meta Company, 2016) have not been chosen for the development of the application.

Consideration of the above criteria leave devices such as the Oculus Rift, HTC Vive, Razer OSVR Development Kit (Razer Inc, 2016), Samsung GearVR, Google Cardboard (if used with plastic headmount) and Wearality Sky (when attached to hat and not handheld; Wearality Corporation, 2015) as potential hardware for displaying visual stimuli of the Virtual Classroom.

Auditory information is a key element of the Virtual Classroom for delivering distractions to the user. The spatial location of each audio cue is vital for systematically testing the user's spatial attention. Modern game engines usually support the spatial presentation of audio sources. Thus, auditory content delivery needs to support spatial audio. While some HMDs already have headphones included that support spatial audio, external headphones can usually be added to a VR/AR system without any problem.

2.4 Choice of User Interaction

Recording user responses is vital for any cognitive assessment. The Virtual Classroom requires the user to respond to stimuli on the blackboard and to respond to input from the teacher.

If deployed as a mobile HMD, user input can be implemented through Bluetooth gamepads, keyboards or similar controllers. Speech recognition on Android or iOS are also valid options. In either case, latency variability needs to be taken into account when measuring response timings, as Bluetooth connections and voice recognition both add a slight delay to the response of the user. Desktop deployment provides more user input options, because many wired controllers, mice and keyboards with low input latencies are available. Desktop deployment also adds more options for writing, hand- and tool-tracking (i.e. pen) that can be used as a naturalistic response mechanism for the student user or as a detection method for fidgeting and motor activity. Such devices include writing tablets from companies like Wacom (Wacom, 2016) and hand-tracking devices such as the Leap Motion (Leap Motion Inc, 2016).

Head-direction, as measured through head-tracking, can also be used as a means of user input. Facing other students can reliably be detected and used to start distracting animations. Head-direction is also an important variable for determining whether the user was looking at the blackboard when task-related stimuli were presented and potentially omitted by the user. The downside to using head-direction as an approximation for gaze-direction is that it is unknown what exactly the user was looking at or even whether the user's eyes were closed. Eye-trackers are not commonly integrated in HMDs yet, but several companies (e.g. Tobii AB, 2015; Fove Inc., 2016) are working on advancing foveated rendering, which requires eye-tracking to adaptively change the resolution of the displayed image based on the user's gaze-target.

Lastly, the clinician's, researcher's or educator's interaction with the system need to be considered. It is assumed that this user group requires a visual display of what the student user is experiencing in real-time. On a desktop VR system, the PC's monitor will usually display the point-of-view of the HMD. For mobile systems, the smartphone's display can be streamed to a TV via devices like Google Chromecast (Google Inc, 2016). Alternatively, Bluetooth or WifiDirect can be used to stream data from the smartphone to a second device that serves as the clinician's / researcher's / educator's interface and live feed of the application. Further, it needs to be decided whether the clinician / researcher / educator requires direct control over the application or whether the scenario is fully automated. For the Virtual Classroom these controls can include triggering distractions or changing the parameters of the primary task on the blackboard. It has to be noted that in some clinical or military environments the communication via Bluetooth or WifiDirect are prohibited and thus, mobile deployment or communication between multiple devices have to be ruled out as possible hardware choices. This limitation does not apply to the Virtual Classroom when used in a therapist's office or lab setting.

The choices presented in the previous steps are summarized in Figure 3.

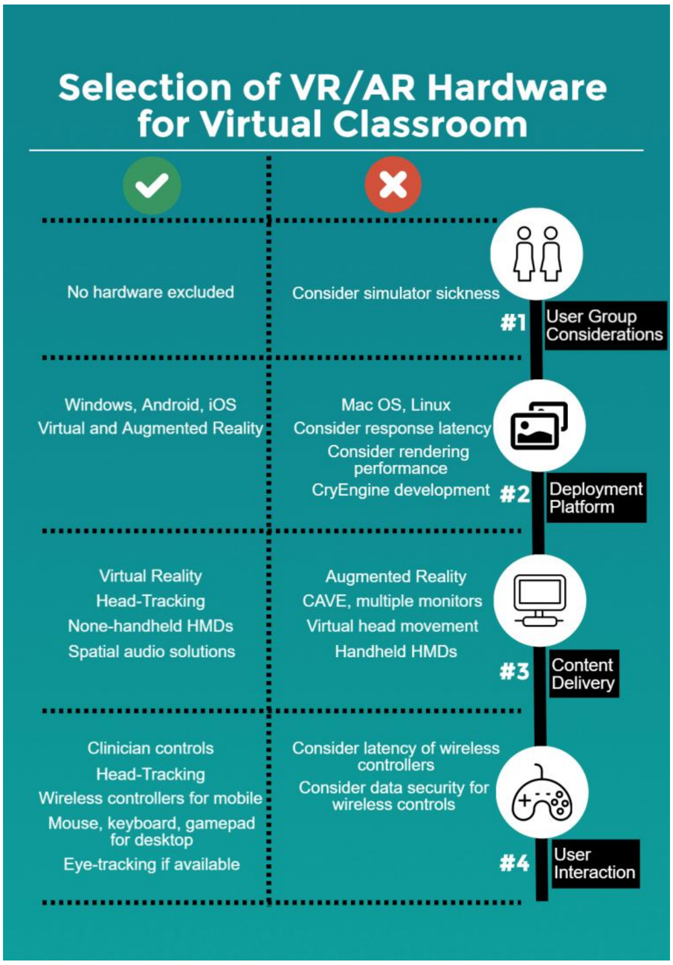

Figure 3. *Hardware selection process for the Virtual Classroom.*

3. CONCLUSION

The example of the Virtual Classroom application can be applied successfully to different use cases with various user populations, even after excluding many technologies and VR/AR devices. Applying the selection process to this example project, two main configuration scenarios emerged for clinical and research use. When space and mobility are of less concern, a Windows desktop system with current HMDs such as the Oculus Rift and HTC Vive seems optimal. The clinician, researcher or educator can interact with the application through a normal PC monitor and use mouse and keyboard to change assessment and training scenarios. For improved mobility and flexibility, smartphone-based HMDs such as the Samsung GearVR are the preferred choice. The clinician, researcher or educator can monitor and interact with the application through a wireless connection of a separate tablet or laptop.

The Virtual Classroom is currently being used in three research trials. One trial investigates the influence of seating position during a simulated math class on student attention and retention of presented material. A second trial is testing the effect of a neurofeedback training in the Virtual Classroom on children diagnosed with ADHD. Lastly, the Virtual Classroom is utilized as a training for teacher trainees to provide hands-on scenarios for diagnosing disorders such as ADHD or dyslexia (Klingsieck et al., 2015). The Virtual Classroom of the first two trials presents the user with a student’s perspective and the last trial puts the user in the perspective of a teacher who can observe the classroom and interact with students. The first two trials leverage the Oculus Rift and a Windows PC and the last trial aims to make the Virtual Classroom accessible to a wide range of Windows-based laptops and desktop PCs.

The described selection process was devised to assist researchers to make decisions about hardware and software for use in Virtual Rehabilitation applications. Obviously, just as rehabilitation is not one size fits all, these solutions are not one size fits all. VR and AR applications can improve rehabilitation by offering flexible, tailored tools that can provide multimodal feedback, quantitative measurement and user engagement. It is important to consider the technical aspects and how decisions about hardware and software will ultimately have an impact on the final product in this fast-paced market of VR and AR technologies.

The authors have no affiliations with or financial investments in any of the mentioned companies or products and no endorsement of specific products is intended.

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Usability and performance of Leap Motion and Oculus Rift for upper arm virtual reality stroke rehabilitation

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ABSTRACT

Intensified rehabilitation is important for stroke survivors but difficult to achieve due to limited access to physiotherapy. We present a virtual reality rehabilitation system, Target Acquiring Exercise (TAGER), designed to supplement center-based physiotherapy by providing engaging and personalized exercises. TAGER uses natural user interface devices, the Microsoft Kinect, Leap Motion and Myo armband, to track upper arm and body motion. Linear regression was applied to 3D user motion data using four popular forms of Fitts's law and each approach evaluated. While all four forms of Fitt's Law produced similar results and could model users effectively, it may be argued that a 3D tailored form provided the best fit. However, we propose that Fitts's Law may be more suitable as the basis of a more complex model to profile user performance. Evaluated by healthy users TAGER proved effective, with important lessons learned which will inform future design.

1. INTRODUCTION

Upper limb rehabilitation following a brain injury, stroke, or other condition affecting upper limb movement, is carried out by occupational therapists and physiotherapists to recover and adapt the patient's movement and improve Activities of Daily Living (ADL). Research confirms that rehabilitation is capable of improving arm function during both the early and late phases of stroke. However, effective therapy must be intense and requires the repetitive practice of task related movements and actions (Kwakkel et al. 1999). Repetitive task training involves intensive repeated practice of relevant functional tasks and is thought to reduce muscle weakness and form a physiological basis of motor learning (Bütefisch et al. 1995).

Virtual reality (VR) has significant potential to support self-management of such rehabilitation, in that it allows individuals to interact and train within interesting, realistic virtual environments. It provides users with the opportunity to practice intensive repetition of meaningful task-related activities necessary for effective rehabilitation (Crosbie et al. 2007). A recent Cochrane review of 12 trials involving 397 participants for the upper limb, stated that the use of VR and interactive video gaming may be beneficial in improving upper limb function and ADLs; when used as an adjunct to usual care or when compared with the same dose of conventional therapy (Laver et al. 2015). This Cochrane review concluded that it is unclear at present which characteristics of VR are most important. However, they emphasized the need for pilot studies assessing usability and validity as part of the development process if designing new VR programs for rehabilitation purposes; these studies may also afford insight on the key VR characteristics for retraining of movement e.g. in reach and pointing tasks.

In this paper we present a multi-sensory VR system, Target Acquiring Exercise (TAGER), and evaluate its usability and performance for upper limb rehabilitation. We evaluate Fitts's law as the basis of an adaptive system to model movement performance for reach and touch tasks in a 3D virtual space. TAGER evolved from previous VR and augmented reality (AR) testbeds developed by our research group (Burke et al. 2009) and particularly from initial research undertaken with the Leap Motion controller (Charles et al. 2014). TAGER utilizes several natural user interface (NUI) devices to track the user, namely the Leap Motion, Microsoft Kinect V2, and the Myo armband, and affords the option of wearing of a VR headset (in this experiment the Oculus Rift DK1). In the experiment outlined in this paper, the tasks comprise basic 3D reaching and pointing exercises so we can effectively evaluate the system and user model. The experiment reported here focused on testing with healthy users to help us evaluate the user interface ahead of planned experiments with impaired users, and has helped us refine the user profiling system. We took a participatory approach to system and experimental design, engaging with physiotherapists and occupational therapists in local health trusts, namely the Regional Acquired Brain Injury Unit (Musgrave Hospital, Belfast), Stroke Unit at the Royal Victoria Hospital (Belfast), and Brain Injury Matters (Belfast).

2. RELATED WORK

A core interest in VR as a rehabilitation tool is due to its potential to provide an enjoyable experience. However, VR systems are flexible technologies supporting feedback, capability adaption, high intensity, repetitive, functional exercises to encourage motor control and motor learning. There are an increasing number of studies that are particularly focused on using commercially available hardware devices to support upper limb rehabilitation (Laver et al. 2015). However, new cheaper, high quality commercial hardware, such as Leap Motion and the Myo, offer new opportunities for effective center and home based self-managed rehabilitation. When combined with other existing technology, they have the potential to improve accuracy and reliability of performance monitoring, although research is limited on these technologies. Feedback is particularly important to patients and VR systems have the potential to excel in providing rich, informative, personalized, just-in-time responsive feedback. Feedback cues in VR environment, when appropriately designed, can help users improve interaction performance. Rehabilitation systems have implemented multi–modal cues such as visual, tactile and auditory cues. The organization of movement is related to the quality of the viewing environment, particularly visual cues between the user's arm and the objects to improve spatial awareness (Levin et al. 2015). Tactile cues have also been reported to improve motor performance (Cameiroa et al. 2008), they are mainly used to help users identify success of interaction. Positive auditory cues provide user motivation to perform intensified repetitive tasks, represent temporal and spatial information very well and improving motor learning (Avanzini et al. 2009).

Adaptation is an important usability factor within a VR rehabilitation user interface design, to enable a system to adapt to a diversity of motor control capabilities and as rehabilitation progresses (Burke et al. 2009). This is important as a user may become frustrated if the tasks are too difficult or bored if tasks are too easy; thus maintaining engagement which is vital in rehabilitation. Techniques proposed in the literature for adaptive VR rehabilitation systems include fuzzy logic and Fitts's Law (Karime et al. 2014). Fitts's Law is well known in the user interface community and has also been applied with the stroke rehabilitation (Zimmerli et al. 2012) context. Fitts's Law models a user's motor skills by predicting the time to reach and touch a target based on a target's size (*W*) and the distance (*D*) from an origin (Equation 1). The logarithmic element of the equation, known as the "Index of Difficulty" (*ID*), is used to quantify the difficulty for reaching a particular target. Thus, the movement time (*MT*) required to acquire a target is linearly dependent on *ID*, where smaller and further away objects are more difficult to attain.

$$MT = a + blog_2\left(2\frac{D}{W}\right) \tag{1}$$

Equation 1 shows Fitts's original equation but other researchers have devised variations of the equation to provide an improved model in different situations. Two popular adaptations of Fitts's Law are Shannon/McKenzie (equation 2) and Welford (equation 3), which were originally tailored to quantifying human movement behavior for 1D and 2D tasks. They have also been applied to 3D environments, but recently new forms of the equation have been devised to more accurately represent 3D interactive movements. Equation 4 (Murata & Iwase 2001) adapts Shannon/McKenzie (2) to include the addition of a movement direction parameter, to account for the consideration that MT is also dependent on the user's angle of motion (θ) from an origin to a target.

$$MT = a + blog_2\left(\frac{D}{W} + 1\right) \tag{2}$$

$$MT = a + blog_2\left(\frac{D}{W} + 0.5\right) \tag{3}$$

$$MT = a + blog_2\left(\frac{D}{W} + 1\right) + \sin\theta \tag{4}$$

3. EXPERIMENTAL DESIGN

The research described within this paper has an exploratory emphasis and focuses on investigating VR NUI design – particularly the reliability of tracking systems and the modelling of user motion via Fitts's Law and its variants, the aesthetic design of multi-modal cues, and the usability and acceptability of the VR headset. The purpose in conducting this research – and the subsequent follow up with impaired users – is to ensure that the underlying interactive interface and adaptive motion tracking system is as robust as possible before adding further user interface elements, game components, and connected health systems. Ultimately our intention is that the system will be robust enough for unsupervised usage by stroke patients.

3.1 Participant Recruitment

Healthy participants were enrolled in the experiment from students and staff at Ulster University. Inclusion criteria included that participants should be 18 years old and over, have no vision issues (e.g. blurred vision, color distortion, light sensitivity, depth perception), nor any disability that affected the upper extremity. Participants completed a questionnaire to gather information regarding IT and gaming literacy and to determine inclusion in the experiment.

3.2 Target Acquiring Exercise (TAGER)

TAGER is a custom designed 3D pointing exercise for upper limb rehabilitation, designed based on requirements from research (Hochstenbach-Waelen & Seelen 2012) and clinician involvement. TAGER utilizes a number of technologies that work together to monitor and provide feedback to users while completing upper arm rehabilitation tasks. The Leap Motion controller is a small desktop NUI which contains an infrared camera specifically design to track fingers, hands and arms. It tracks up to 20 bones per hand, at up to 200 frames per second with 150° field of view and approximately eight cubic feet of 3D interactive space. TAGER uses the Leap Motion as the main interactive device within the virtual world for tracking motion and facilitating target acquisition. Microsoft's Kinect V2 is similar to the Leap Motion, though instead of sensing hands it senses motion of the human skeleton. We collect data of all joints in the upper body in motion with the goal in a future version providing guidance on suitable functional task movements and other factors. It is natural for a person with an affected limb to move their whole body forward rather than extending their arm, especially if tired. As this would hinder improvement through the rehabilitation process, system feedback and guidance can be crucial. The Oculus Rift DK1 (VR Headset) contains a 7″ screen with resolution of 1280×800 (16:10 aspect ratio) and a 90° field of view, and enables head positional and rotational tracking allowing the user to control the view point within the virtual worlds. The Oculus is investigated in this experiment to determine if it is acceptable for use and could potentially be used to increase spatial awareness. The Myo armband slides on to the forearm, and uses electromyography (EMG) technology with eight medical grade EMG nodes attached, that read electrical signals from the muscles. The Myo armband also includes an accelerometer and gyroscope to track movement and orientation on the forearm. The use of the Myo armband here is to collect data to be stored for future studies helping identify changes in muscles, which could highlight factors such as fatigue and correctness of exercise. The Myo armband also includes tactile mechanisms for example, vibrations on the skin, which are used to introduce tactile cues into the system.

3.3 Experimental Setup

The experimental process comprised three stages: (1) a training stage which gives the participant ten minutes to familiarize themselves with the technology and practice interaction. The training tasks are very similar to the real trials. Through system testing and observing with users before the actual experiment it was decided that ten minutes training would be sufficient enough for the participant to familiarize themselves but not cause fatigue. After training, the patients are given a short two minutes' rest period before the next stage (2), which is the complete TAGER trial. In stage 3, after each user completes the trial, a short discussion takes place gathering any comments the participant might have and for the investigator to ask questions related to the user's experience of the system. Throughout the experiment the participant is closely monitored by the investigator and provides assistance if any problems arise. The experiment is strictly controlled; the location of each trial was always the same as well as the equipment used. The equipment is arranged exactly the same for each patient ensuring no other possible variables could affect the collected results. The experiment was conducted on a commercial 64 bit Windows 8.1 laptop with Intel Core i5 @ 2.5 GHz, 8GB RAM, and 500GB hard drive attached to a 22″ monitor at (1920x1080) resolution. Figure 3 illustrates the layout of the environment.

TAGER's 3D virtual environment is the inside of a basic walled room (no wall at the front) with a large start button on the floor of the room, the user is prompted to push the button with their virtual hand to begin. The icosahedron shape is purposely chosen as the target object for its geometric properties, particularly as visual cues are required to enhance spatial awareness. With changes in viewing angles, objects with a greater number of faces and edges such as icosahedrons, give greater clarity of visual cues (Powell & Powell 2014). Each repetition (4 per level) contains 27 icosahedrons to target, all at different locations, a total of 108 per level (4*27). When the start button is pushed a single icosahedron appears randomly at any of the 27 locations. The user moves their virtual hand around the 3D environment touching each icosahedron that appears. When touched the icosahedron disappears and another icosahedron appears on the floor of the room at the location of the start button. We call this object the origin; this approach is used to provide consistent movement trajectories. All objects are intentionally placed at fixed locations and at fixed distances from the user's view to simplify analysis.

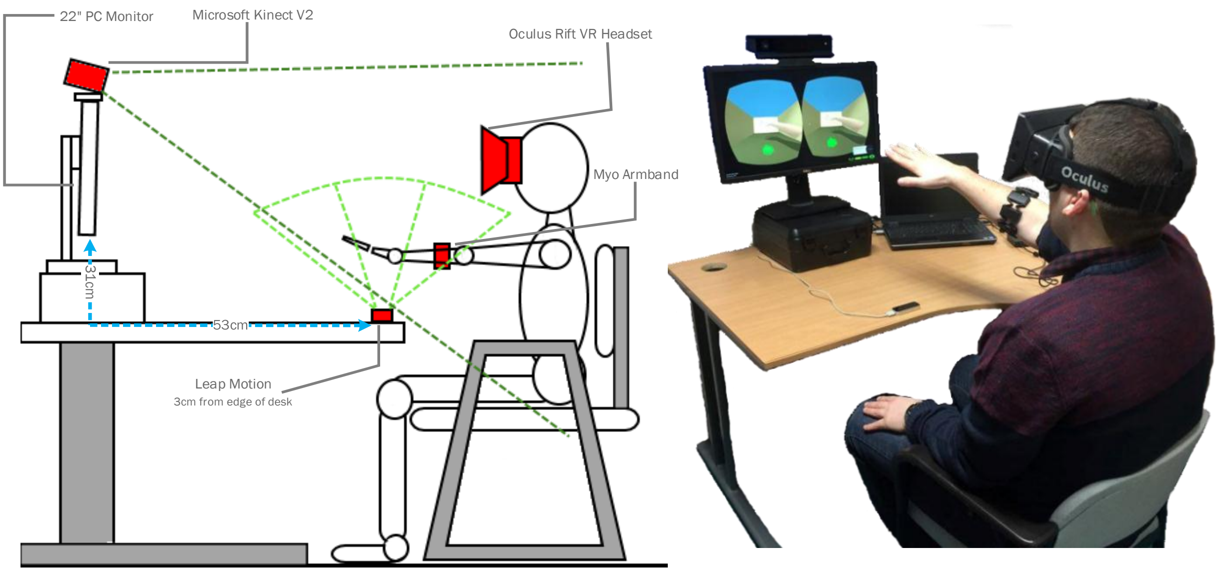

Figure 1. *Experimental setup.*

The TAGER VR software for this research was constructed with ten levels; the first and last levels are identical enabling us to compare performance over the period of the session – considering learning and/or fatigue effects. All other levels are unique in terms of scene attributes such as target object scale, multi-modal cues and VR headset use; to investigate the impact they have on movement behavior (Figure 2). Levels 2-9 are randomized per user to eliminate potential bias in the ordering, a rest period is given between each level and repetition. The unique levels comprise different combinations of scene attributes such as shadowing and proximity color change for visual cueing. Tactile cues are included using the Myo Armband where a vibration is sent to the user's arm upon successful target acquisition. We also change the scale of the objects; objects are sized accordingly as 2, 3.5 and 5cm. Objects are scaled to discover the impact it has on cues. For example, larger objects are expected to give greater clarity to visual cues and thus quicker arm kinematics. These scene attributes help build knowledge on the impact they have on arm kinematics, spatial awareness, movement speed and accuracy.

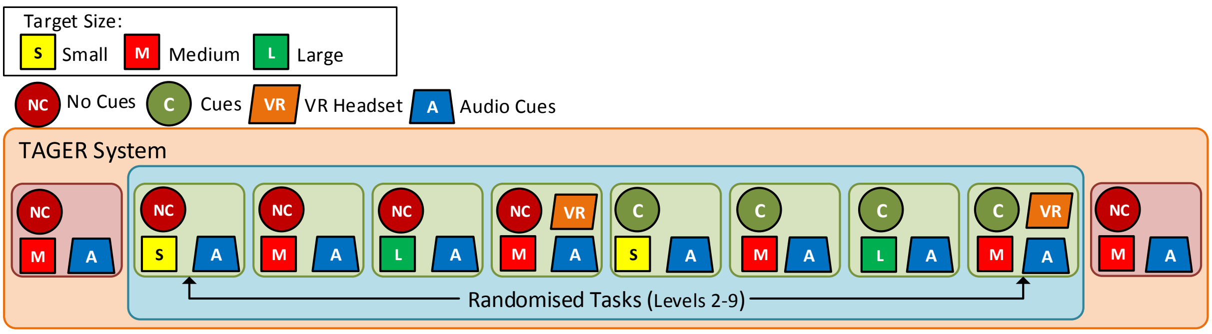

Figure 2. *TAGER's level layout and scene attributes.*

4. RESULTS

The above experiment was undertaken to investigate core aspects of TAGER. After the experiment, participants were invited to comment on usability and perceived effect on performance of the use of the VR headset, the Leap Motion, and user interface. Data was recorded every tenth of a second from all input devices and *MT* calculated and recorded to file automatically from tasks for analysis of the movement models. Of the 26 participants, three were excluded from data analysis due to missing data or system issues (loss of tracking).

4.1 *Usability*

Of all 26 participants, 77% reported that their experience using the VR headset was enjoyable, no motion sickness or other health related effects were reported. 43% of people commented that they perceived their performance to have improved while wearing the headset, while 50% said that they needed time to adjust when first wearing the headset. We compare user performance between the VR headset and monitor use, with and without cues. We used a paired t-test to determine significant differences between users average *MT*, we found no significant difference in: Cues (T=1.681; DOF=21; p=0.053) or No Cues (T=1.591; DOF=21; p=0.063), though there was a consistently slower user response when using the headset (Table 2). In other words, the participant's subjective experience was at odds with the objective measurement. Though this is not a significant issue so long as the effect is consistent among users, and it is a consideration for future interaction design. Discussion with health professionals reinforced the importance of aesthetic cues in rehabilitation VR system design. We provide feedback on target proximity and acquisition through lighting and shading, as well as vibration from the Myo armband. Figure 3 shows variation of interaction difficulty with cues (C) and without cues (NC) for different sized objects (large – LRG, medium – MED and small – SML). While results are generally as expected – i.e. cues support improved efficiency in target acquisition. It is not clear that cues improve performance for MED cue acquisition and more investigation is required. More detail will be covered on the effect of cues in the next sub-section.

Table 2. *Mean movement time comparing VR headset and PC monitor: cues(C), No cues (NC).*

Exercise	VR (NC)	Monitor (NC)	VR (C)	Monitor (C)
Mean MT (ms)	1174.2	1107.4	1165.0	1115.4
T-test P=(0.05)	0.063		0.053	

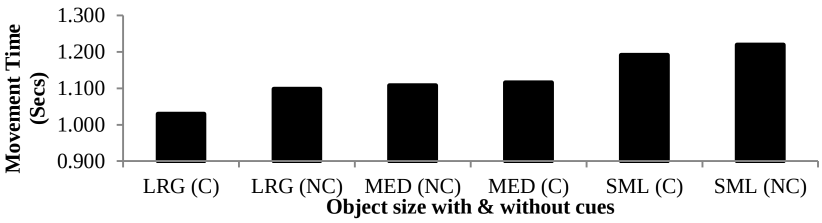

Figure 3. *Variation of Interaction Difficulty arranged by magnitude.*

An objective way to evaluate system feature effectiveness in TAGER is to record target acquisitions (hits) against movement times. A target has been successfully acquired when the user's hand collides with the surface of the target object without leaving the Leap Motion's detection area. Hits are classified as unsuccessful when the user's hand leaves the boundaries of the Leap Motion's detection area before hitting the target, users are required to return to within the boundaries to hit the target. Users cannot progress until they acquire the current target, even after registering an unsuccessful hit. It was found that targets positioned at the center depth (relative to the user) were more successfully acquired – a mean of 29 per task over all participants (Front = 22, Back = 26). Closer objects appear to have been harder to attain, suggesting we may need to consider moving the minimum distance further away (along the z-axis) or move objects closer to the z-axis along the x and y axes. The later suggests a cone area (Cha & Myung 2013) for object placement – with the cone pointing towards the user – rather than a cuboid (which maps well to the Leap Motions detection area). This might account better for arm kinematic differences in attaining targets in close and far locations. Users attained targets in all areas with reasonable success, though on average there were 31(28%) unsuccessful acquisitions per level from a total of 108 targets. This may be considered to be quite high, if the Leap Motion is mounted on the VR headset, pointing forward (users facing direction) it could possibly provide a more natural interactive space, and reduce unsuccessful acquisitions. TAGER's experimental design implements two identical levels one at the beginning and end of the experiment, enabling investigation of the potential learning effects indicated by improved performance or user fatigue resulting in performance decline. The mean completion times for all users for the start task was 1257.8 ms while for end task completion times it was 1081.4 ms suggesting that, despite having 10 minutes training time at the start, user performance significantly (T=4.60, DOF=21, p=7.7E-05) improved over the experiment. There are also some indications of fatigue (or loss of concentration) among several users. Analysis of experimental data in the next section enables us to investigate the intricacy of user profiles.

4.2 Model Effectiveness

As outlined earlier we recorded user motion data in reaching from an origin to touch an object target at various distances. Figure 4 shows the lines fitted to the data through regression for four well known forms of Fitts's Law.

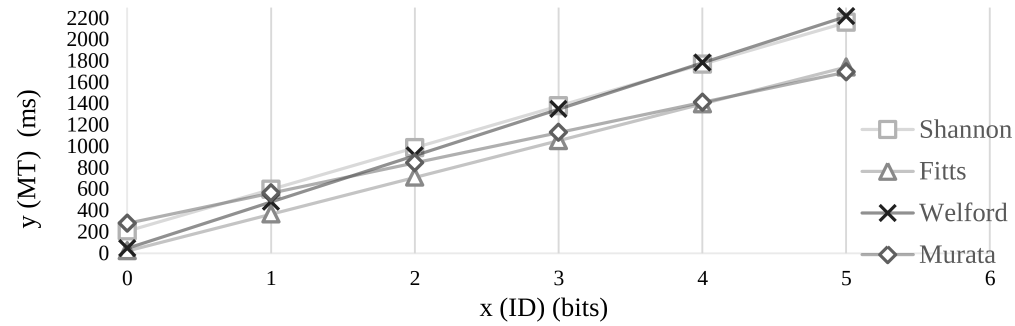

Figure 4. *Regression Line from our Data for Four Popular Variants of Fitts's Law.*

Table 5. *Average y-intercept across each level for all equations.*

EQ	SML (NC) (ms)	SML (C)	MED (NC)	MED (C)	LRG (NC)	LRG (C)	VR (NC)	VR (C)	Start	End	Overall Mean
(1)	189.3	77.4	270.7	161.6	392.7	343.4	70.6	-41.6	254.1	356.7	207.5 ± 89.3
(2)	-25.3	-152.2	95.9	-30.8	254.4	209.2	-107.9	-293.5	49.6	213.2	21.3 ± 110.9
(3)	86.4	-37.9	121.5	-7.5	210.2	166.6	-122.8	-250.8	74.7	224.4	46.5 ± 107.0
(4)	319.3	203.3	279.9	243.4	357.7	346.6	203.8	185.0	288.3	374.2	280.2 ± 83.6

Table 6. *Average slope across each level for all equations.*

EQ	SML (NC) (ms)	SML (C)	MED (NC)	MED (C)	LRG (NC)	LRG (C)	VR (NC)	VR (C)	Start	End	Overall Mean	Bits Per Sec
(1)	339.3	370.1	355.8	406.2	366.9	356.2	463.7	510.8	427.3	308.4	390.5 ± 46.0	2.5
(2)	315.7	343.2	316.6	358.4	311.0	301.9	392.7	454.3	378.1	271.6	344.4 ± 41.1	2.9
(3)	362.8	396.7	396.6	451.2	421.8	409.4	515.8	566.6	475.7	344.6	434.1 ± 51.2	2.3
(4)	247.7	273.1	275.1	290.5	282.1	261.7	318.5	324.1	322.9	236.2	283.2 ± 32.7	3.5

Tables 5 and 6 show the average regression values of the y-intercept and slope values for the all participants. Murata's 3D equation (4) provides y-intercept values ranging from 196 to 363, which are more representative of human movement response (typically 200 to 300 ms), it also provides a more gradual gradient giving a more appropriate model of *MT* against *ID* (Heiko 2013). Thus, while all four equations provide similar results, we focus on Murata for further analysis. Figure 5 shows typical results with and without cues for large sized targets and Murata's 3D form of Fitts's law. This experiment is fundamentally exploratory in nature. We use Fitts's law and linear regression to develop a user model, which will help us understand how best to create an adaptive system that can personalize interactive tasks. Table 7 provides user profiles from a proposed model comprising parameters such as regression line data, statistics on the residuals of the line fit, task performance and user information. Considering the explicit performance metrics (hits, movement times), target hits provides an informative statistic and capable users are readily distinguishable from less able. Only one person had a score of less than 500 /1080 with the lowest score 472. The highest score was 900 and the average score was 754.74. Mean hits per person rose from 73.91 at the start to 77.22 at the end from a total of 108. The mean percentage improvement in hits over the experiment was 6.92% illustrating diversity of learning and fatigue effects among participants. The mean percentage reduction in *MT* was 13.79%. Average change in line fit according to R^2 and associated values are not significant (due to the spread of data values there are a number of valid lines). Change in hits between the start and end tasks in the experiment are potentially revealing of a possible learning effect

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(improvement) or mental/physical fatigue. A learning effect provides a challenge to adapting task difficulty per user – it is preferable to adapt difficulty based on Fitts's law only after the learning effect stabilizes. Nonetheless, it is helpful to identify that a user remains in a learning phase, so that additional support can be provided. However, *MT* and hits should not be considered independently, as some users may slow down deliberately in order to improve hit performance. The mean slope gradient decreased by 26.85% and the mean intercept by 29.82%. Shallower slopes indicate a more skilled response as there is less difference between acquiring close and far objects, while a rise in the intercept value moves the intercept closer to physiological reflex norms (generally between 200 and 300 ms). Additional user profile information can be gained from the residual statistics of regression lines and the changes between start and end tasks. Mean standard deviation dropped by 19.28% and mean variance also fell by 32.49%, suggesting that on average users were becoming more accurate. Range dropped by 10%, supporting this proposal. Kurtosis of residuals increased by over six times the magnitude (positive values) suggesting an increased number of data points with a small deviation from the regression line. On the other hand, skew also increased 44.4% (also positive), which after examining the regression graphs of users we believe is due to users overshooting the target position and having to change direction. From our results we did not identify a strong relationship between performance and user age or gender. Figure 5 shows Murata 3D linear regression model of user 1009's movements per location for acquiring large targets with and without cues.

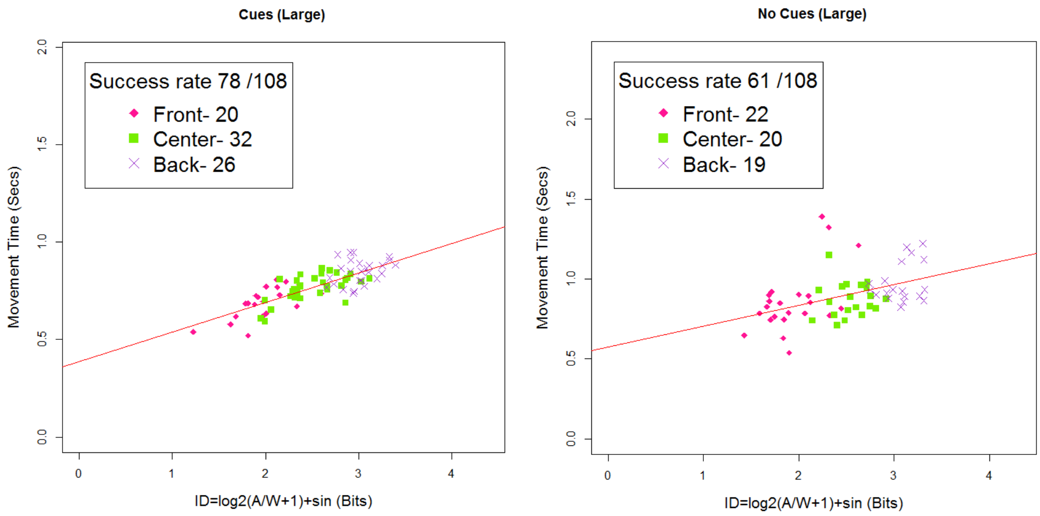

Figure 5. *Murata's 3D model of movement without the VR headset. Successful targeting of objects is distinguished by 3 locations in the virtual scene relative to the user: front (red diamonds), center (green squares), and back (purple crosses).*

Data from seven of the twenty-three participants provided a poor fit to the model based on start task motion data. Data after the end session from five participants had a poor regression fit, though two of these participants were different from the seven identified from the start data. These two people may have been overly tired or bored, rather than being incapable, highlighting the need for intricacy and careful analysis of the profiles. To consider this further it is necessary to examine a few representative individual user profiles (Table I). User 1026 is an informative example, who started well with a successful profile but whose hits and mean MT declined significantly during the end task. Despite having residual statistics during the end task that show less variability (indicating more effective target acquisition for a significant number of targets), hit score actually decreased, while skew and kurtosis both increased (suggesting more overshooting of the target), and R^2 and the associated P-value suggested an unreliable regression fit (possibly due to an increase in outliers). 1026's mean MT dropped by a 23.96%, which suggests, with respect to the profile context, that during the end task this user may have adopted a high-risk strategy. This is in contrast to 1019, who appears to have become more conservative, and by moving slower (13.64% increase in mean MT) improved their hit score by 12.82%. This considered approach by user 1019 and other participants seems to improve the likelihood that the user motion data corresponds to Fitts's law (and variants). User 1002 had the weakest start having the lowest number of hits in the initial task but improved hit performance by 50% and mean MT by 31.59%. However, even by the end task this user's motion could not be applied to Fitts's law reliably and they had less than a 50% hit success rate in the final task. User 1023 exhibited arguably the most sustained success, having the highest overall hit success and start and end scores of 90 and 91 respectively and overall an improved profile (based on regression values). As with user 1019, 1023 is not particularly fast but improved speed over the experiment. Three participants got slower over the experiment and all of these achieved higher scores in doing so. Five participants got lower hit scores and all of these but one had much less adequate regression fit and three of these exhibited faster mean MTs. Further investigation is required to understand whether users with these profiles exhibit a decline of interest – the tasks were repetitive and several of these participants were quite skilled at the tasks – or due to mental/physical fatigue.

5. CONCLUSIONS

In this paper we presented an initial version of TAGER VR upper arm stroke rehabilitation system, which utilizes several low cost, commercially available input devices and a VR headset. We reported on an experiment that focused on usability of the system and on the use of various forms of Fitts's law to linearly model user motion - movement time against an index of difficulty – for reach and touch tasks in a 3D environment using a Leap Motion controller as an input device. Most users enjoyed using the Leap Motion device and perceived tasks to be easier with the VR headset on. No motion sickness or other negative health related effects were reported. The importance of cues has been reported widely in the literature and while our results show a general improvement in object acquisition with visual cues, we found the impact on targeting medium sized objects to be unclear. We outlined results from fitting user motion data to four forms of Fitts's law with each of the equations exhibiting similar success. Examining the statistics of the regression process based around Fitts's law we found that these equations could be used to linearly model user motion with the Leap Motion controller in a range of setups including the use of a VR headset. However, the data point variance across the regressed line is quite high and Fitts's law should not be applied as a simple linear model of user motion equally to all users. We recommend that a form of Fitts's law, for example Murata's 3D version, could be used as part of an intelligent system to profile users. Although the motion of most users could be modelled effectively using Fitts's law, we found a few users who found the NUI so difficult that they could not be modelled linearly. Most of these users required more training than we expected but in some cases users appeared to become tired or bored. A more complex profiling system helps to identify training requirements and distinguish between loss of interest and mental or physical fatigue. We intend to develop the profiling system with further experiments and subsequently investigate the system with impaired users.

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Table 7. *User statistics over time including residuals, regression and performance data to define a user performance profile.*

User	1001	1002	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1019	1020	1021	1022	1023	1025	1026
Start (Residual)																							
Standard Deviation	0.354	0.461	0.270	0.352	0.344	0.343	0.300	0.257	0.270	0.321	0.361	0.368	0.448	0.163	0.528	0.293	0.313	0.293	0.203	0.490	0.408	0.343	0.378
Sample Variance	0.125	0.213	0.073	0.124	0.118	0.117	0.090	0.066	0.073	0.103	0.130	0.136	0.201	0.026	0.279	0.086	0.098	0.086	0.041	0.241	0.167	0.117	0.143
Kurtosis	0.085	-1.141	0.082	-0.964	-0.609	-0.019	-0.209	0.031	-0.468	-0.61	-1.051	-0.238	-0.773	2.559	-0.382	-0.824	-0.331	0.170	0.536	-0.787	-0.262	0.290	0.376
Skewness	0.986	0.394	0.535	0.561	0.486	0.963	0.700	0.996	0.783	0.522	0.740	0.286	0.241	1.703	0.505	0.603	0.394	0.934	1.080	0.359	0.785	0.526	0.980
Range	1.519	1.522	1.431	1.261	1.226	1.367	1.212	1.036	1.024	1.242	1.081	1.558	1.752	0.724	2.464	1.075	1.431	1.272	0.893	1.819	1.594	1.596	1.528
End (Residual)																							
Standard Deviation	0.111	0.275	0.263	0.249	0.338	0.294	0.363	0.194	0.156	0.293	0.400	0.242	0.280	0.117	0.330	0.326	0.420	0.281	0.129	0.391	0.285	0.374	0.235
Sample Variance	0.012	0.076	0.069	0.062	0.114	0.086	0.132	0.038	0.024	0.086	0.160	0.058	0.078	0.014	0.109	0.106	0.177	0.079	0.017	0.153	0.081	0.140	0.055
Kurtosis	5.852	0.985	-0.834	-0.417	-0.470	0.509	-0.860	2.540	2.127	-0.797	0.889	-0.627	-0.160	8.916	1.000	-0.488	1.927	0.943	4.376	-0.802	1.197	-0.594	0.498
Skewness	1.834	1.227	0.721	0.751	0.824	0.943	0.282	1.515	1.573	0.428	0.925	0.187	0.315	2.597	1.067	0.751	0.952	1.111	1.897	0.342	1.143	0.520	1.289
Range	0.657	1.259	0.948	1.027	1.330	1.329	1.419	1.016	0.689	1.108	1.934	0.983	1.321	0.704	1.657	1.382	2.227	1.313	0.737	1.442	1.340	1.688	0.920
Start Regression																							
R^2	0.115	0.076	0.448	0.062	0.036	0.167	0.073	0.228	0.244	0.298	0.023	0.453	0.056	0.124	0.056	0.287	0.343	0.197	0.379	0.040	0.112	0.385	0.189
P-Value	4.05E-03	9.28E-02	4.11E-13	3.52E-02	1.89E-01	1.14E-04	6.28E-02	8.60E-07	1.03E-06	3.12E-06	2.83E-01	1.78E-08	6.18E-02	5.29E-04	3.20E-02	1.04E-07	1.79E-08	8.55E-06	1.72E-10	1.45E-01	1.17E-03	8.35E-10	3.92E-05
Slope	0.268	0.312	0.527	0.203	0.126	0.310	0.189	0.273	0.309	0.416	0.136	0.602	0.235	0.143	0.280	0.406	0.517	0.313	0.339	0.199	0.348	0.587	0.388
Intercept	0.352	0.360	-0.336	0.463	0.813	0.549	0.733	0.268	0.113	-0.100	0.686	-0.289	0.863	0.375	0.761	-0.042	-0.212	0.430	-0.084	0.879	0.475	-0.306	-0.121
End Regression																							
R^2	0.266	0.024	0.186	0.021	0.002	0.116	0.239	0.348	0.111	0.065	0.133	0.446	0.140	0.126	0.290	0.123	0.224	0.328	0.164	0.165	0.392	0.314	0.004
P-Value	3.80E-05	2.54E-01	3.07E-05	2.08E-01	7.45E-01	1.07E-03	4.11E-05	2.83E-09	2.90E-03	5.25E-02	1.53E-03	7.42E-09	2.30E-03	5.48E-04	1.04E-07	5.72E-04	3.18E-06	1.09E-09	6.95E-05	1.18E-03	2.44E-11	1.68E-08	5.77E-01
Slope	0.133	-0.109	0.287	0.085	0.034	0.215	0.387	0.293	0.122	0.169	0.369	0.445	-0.256	0.104	0.405	0.271	0.481	0.422	0.123	0.399	0.509	0.509	0.033
Intercept	0.359	1.220	0.110	0.640	0.933	0.606	0.130	0.092	0.458	0.555	0.023	-0.070	1.747	0.441	0.029	0.333	0.116	-0.058	0.403	0.067	-0.216	-0.010	0.703
Performance																							
Targets Hit(1080)	794	554	828	690	633	821	472	848	818	680	667	638	586	862	856	874	828	879	876	594	900	873	788
Start Hits	70	38	91	72	49	84	48	96	88	64	53	55	63	93	82	86	78	93	88	55	91	80	83
End Hits	73	57	87	78	53	89	64	85	78	58	73	59	64	91	85	93	88	96	91	61	92	87	74
% Change Hits	4.29	50.00	-4.40	8.33	8.16	5.95	33.33	-11.46	-11.36	-9.38	37.74	7.27	1.59	-2.15	3.66	8.14	12.82	3.23	3.41	10.91	1.10	8.75	-10.84
Start Mean Time	1.167	1.292	1.212	1.082	1.203	1.475	1.339	1.063	1.035	1.191	1.111	1.522	1.548	0.797	1.612	1.195	1.391	1.346	0.920	1.483	1.497	1.395	1.055
End Mean Time	0.768	0.884	0.975	0.901	1.039	1.233	1.307	0.952	0.823	1.093	1.178	1.270	0.954	0.755	1.254	1.143	1.580	1.166	0.776	1.293	1.262	1.466	0.802
% Change Mean Time	-34.19	-31.59	-19.49	-16.74	-13.63	-16.37	-2.42	-10.42	-20.50	-8.23	6.04	-16.54	-38.37	-5.33	-22.24	-4.39	13.64	-13.38	-15.66	-12.82	-15.66	5.03	-23.96
User																							
Age	20	20	19	24	22	30	26	42	22	37	44	24	30	26	31	50	66	56	44	46	54	67	24
Gender	F	F	F	M	F	F	F	M	F	F	F	M	M	M	M	M	F	M	M	F	F	M	F

Expanded sense of possibilities: qualitative findings from a virtual self-management training for amputees

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ABSTRACT

This paper presents the procedures and results of a qualitative study that was part of a larger study comparing two methods of accessing a self-management training for amputees: e-learning and a virtual world. Interviews were conducted in Second Life (SL) with ten subjects who completed the training in the virtual world and seven subjects who completed e-learning training. Interpretative Phenomenological Analysis (IPA) was used for qualitative data analysis, leading to the identification of 14 themes within five major categories. An overarching theme of the SL experience resulting from analysis was that of an expanded sense of possibilities.

1. INTRODUCTION

In 2004, the Department of Veterans Affairs (VA) convened a traumatic amputation QUERI (Quality Enhancement Research Initiative) workshop to develop best practices for the new generation of war-wounded service members arriving with major limb amputations from the wars in Iraq and Afghanistan. The problem was community reintegration: when the service members returned to their hometowns and local VA medical centers, they did not fit the treatment profile of the typical amputees with amputation(s) resulting from deconditioning diseases. An additional challenge was there were few of Iraq and Afghanistan amputees, which meant geographically they were far apart. The distance limited peer interactions and clinician specialty skills. It became apparent at the amputation QUERI workshop that peer support for this cohort of amputees was going to have to e over the Internet. Tele-rehabilitation was an option for specialized regional amputee rehabilitation centers to provide training for more rural clinicians. The virtual world was an option for peer-to-peer interaction and self-management training. The US Department of Defense had built two virtual worlds: one for post-traumatic stress disorder (PTSD) (T2 Virtual PTSD Experience) and the Amputee Virtual Environment Support Space (AVESS). The T2 PTSD virtual remains active. When the AVESS project lost funding, Dr. Winkler's research team, which included some of the original AVESS team members, built "Virtual Health Adventures" with virtual meeting spaces and self-management education for amputees. It is intended that "Virtual Health Adventures" would be expanded to provide similar experiences for individuals with other disabilities and their families, for example, diabetic foot ulcers and caregivers of individuals with traumatic brain injury.

A virtual world is a synchronous, computer-based simulated environment, populated by a persistent network of people represented by personalized avatars that simultaneously and independently explore the virtual world, participate in its activities and communicate with others (Aichner & Jacob, 2015; Bartle, 2003; Bell, 2008). Users, through their avatars, are able to socialize, communicate, collaborate and learn with other avatar participants in a three-dimensional environment (Ducheneaut, Wen, Yee, & Wadley, 2009). Second Life® (SL) is the largest of many virtual worlds. Conceptualized by Philip Rosedale who founded Linden Lab, SL offers a persistent, open, unlimited, highly customizable space. The content of SL is created by its users who rent virtual land (islands). The result is a shared space that provides a sense of “being with others,” seeing physical representations of each other, and communicating and acting in that shared space (Thomas & Brown, 2009).

Amputation is a life-long condition. Increased prosthetic use is significantly associated with better psychological ($P<.05$) and social health ($P<.001$) (Gallagher & Maclachlan, 2004), but prostheses and prosthetic needs change over time so that acquiring current and evolving prosthetic and health-related information is an on going process. In addition, social and physical function, and support from others have been identified as important factors in the amputation adjustment process (Gallagher & Maclachlan, 2001). To address these issues, a self-management program was developed. Self-management programs provide patients with the knowledge, skills, and confidence to deal with disease-related problems, e.g. to help patients with managing life roles, negative emotions, comorbidity and secondary conditions (K. R. Lorig, Sobel, Ritter, Laurent, & Hobbs, 2001). The question for this project was how do amputees view engaging in a self-management training program as an avatar. For example, how to amputees view themselves as an avatar performing conditioning and balance activities? The research presented here was part of a larger study that compared two methods of accessing a self-management training for amputees: e-learning using Articulate® software (www.articulate.com) and the SL virtual world. We hypothesized that the virtual world cohort would have better health-related outcomes that the less-immersed e-learning group. The purpose of this paper is to present the findings of the qualitative arm of the study aimed at understanding how amputee subjects experienced SL. The research question asked, “How do participants experience the SL virtual world?”

2. METHODS

Following Institutional Review Board approval, two islands in SL were rented from Linden Lab on which a self-management training, based on Alberto Esquenazi’s Stages of Rehabilitation for Amputees (Esquenazi, 2004), was created. Development of the 17-station self-management training area and virtual world community management were performed by Virtual Ability, Inc.

2.1 Subjects and Recruitment

Participation in a semi-structured interview was included in the informed consent document for the larger study. Because the interviews were held in SL for the purpose of anonymity and confidentiality, the first ten amputee subjects randomized to the virtual world group who completed the study were invited to participate in the interviews. Amputee subjects who chose to experience the virtual world intervention as an avatar after completing the study as a subject randomized to the control e-learning group were also invited to participate in the interview. Seven amputee subjects from this group participated in interviews for a total of 17 interviews included for analysis in this paper. No subjects declined the interview. See Table 1 for a description of subjects who participated in the semi-structured interviews.

2.2 Theoretical Approach

The methodology employed for the qualitative component of this study was that of Interpretative Phenomenological Analysis (IPA) (Smith, 2009). With its focus on lived experience and interpretation of meaning, IPA has broad applicability across the social, health and human sciences. In particular, phenomenology is increasingly being used by occupational therapists and occupational scientists as an approach to understand the individual’s unique experience within the context of his or her environment (Clarke, 2008). With its focus on understanding experience and meaning, this approach is well suited to evaluating participants’ experiences with the virtual environment space. The IPA approach is inductive and iterative in nature, allowing ideas and themes to emerge from the participants’ personal accounts rather than imposing a predetermined theory. However, the theoretical framework for the methodology itself is one that draws upon and links phenomenology, hermeneutics, and idiography, as the approach focuses on lived experience, emphasizes the role of interpretation, and acknowledges the significance of individual experience (Cooper, 2014).

2.3 Procedure

Subjects were invited to participate in the semi-structured interviews by PI Winkler upon completion of post-training data collection. Interviews were performed in SL by Al Hall, as part of his doctoral research. PI Winkler met subjects in SL then invited them to the virtual conference room where they were introduced to Al, through his avatar. Interviews were performed using the text chat feature. The text served as the interview transcript.

Table 1. *Description of sample.*

		SL n=13	e-learning n=4
Age		52	62
Race/ethnicity	White	13	3
	Black	0	1
Gender	Male	10	2
	Female	3	2
Amputation	Unilateral UL	2	0
	Unilateral LL	10	3
	Bilateral LL	1	1
	Unilateral UL & Bilateral LL	0	0
Years since first amputation	0-5	9	3
	6-10	1	1
	11-15	1	1
	16-20	1	0
	>25	1	0
Etiology	Trauma	4	0
	Dysvascular	3	0
	Disease	6	4
Prosthetic use	Daily	9	3
	Weekly	0	1
	Did not use prosthesis	4	0
On computer	Hours per week	29	29
Prior experience with VW		1	0

2.4 Analysis

Co-I Cooper conducted the qualitative data analysis. Data analysis in IPA includes the following steps: a) reading and re-reading of the transcript; b) initial noting and coding of the data; c) developing emergent themes; d) searching for connections across emergent themes; e) moving to the next case; f) looking for patterns across cases; g) developing a theoretical structural description of the experience (Smith, 2009). Initial noting includes three stages of coding in which the researcher notes descriptive, linguistic, and conceptual comments throughout the transcript. Each stage of noting has its own purpose and focus: descriptive comments capture what the participant has experienced; linguistic comments convey the participant's meaning-making process through linguistic indicators such as metaphors, repetition, or capitalization for emphasis; and conceptual comments identify initial possible themes and patterns in a tentative manner, subject to further analysis and interpretation. The themes developed through IPA analysis reflect the focus on experience and meaning, as illustrated below in the results section.

3. RESULTS

Analysis of the qualitative data collected through interviews in SL resulted in the development of 14 themes within 5 major categories. The 5 major categories were: 1) General Experience of Second Life; 2) Experience of Using Avatar; 3) Experience of Training Format; 4) Perceptions of Training Content; and 5) Perceptions of Training Needs of Friends and Family. Between 2 and 4 themes were grouped under each of these categories. In presenting these themes below, words in quotation marks are taken directly from participants in order to retain their voice, in keeping with standards of qualitative reporting.

3.1 General Experience of Second Life

Theme 1. "Learning Curve"

Participants found that it took some practice to become comfortable navigating within Second Life. For almost all participants, this was their first experience in a virtual world. Several noted that they found the Second Life technology somewhat difficult, whether logging in or finding locations. Participants noted that it became easier to maneuver within Second Life with practice.

Theme 2. "An Amazing Experience"

Participants expressed overwhelmingly positive emotions about their experiences in Second Life. In spite of the learning curve and technical difficulties referred to above, participants used very positive language to express their feelings about their experience in Second Life, including "fun," "thrilling," "intriguing," "amazing," "incredible," and "novel."

Theme 3. Second Life a Freeing Environment

In addition to finding Second Life fun and intriguing, participants spoke of it as an environment that provided a "release" from life in the real world. Several participants noted that spending time in Second Life was an "escape," and referred to wanting to visit more often. Participants noted that one can get "lost" in Second Life, both in terms of not being familiar with the sites they visited, and also in terms of becoming so absorbed in the virtual world that they lost track of how much time was passing. Several participants spoke about the ability to do things in Second Life that they could not do in real life, and the "freedom" they felt.

3.2 Experience of Using Avatar

Theme 4. An Enjoyable Challenge

Although some participants spoke of having difficulty maneuvering the avatar, they enjoyed using one. The challenges most frequently referred to were dressing the avatar and sitting down. Several participants spoke of enjoying doing things through the avatar that they could not do in real life, such as flying. Several participants noted that they liked the experience of going through the training as an avatar.

Theme 5. Identification with the Avatar

Participants found great significance in using an avatar. Several noted that they like the "idea of having an avatar." Participants expressed strong identification with their avatars. One stated, "I felt like the avatar was me." Several stated that seeing their avatar with all four limbs made them feel "normal" or "like a whole person." One participant referred to liking "seeing legs again."

Theme 6. Expanded Sense of Possibilities

In addition to identifying with the avatar, participants seemed to find inspiration from the avatar's actions. Participants felt less limited as a result of using the avatar. One noted that seeing the avatar "reinforced that I don't have limits." Another commented that he could be fearless as an avatar. Several participants observed that they wished they could do in real life what they could do as an avatar in Second Life. As one participant commented, "I liked being able to do things that I can't do in the real world." One participant perceived the avatar's mobility as transferable to real life, noting "The mobility of the avatar actually transfers to you if you allow it to."

3.3 Experience of Training Format

Theme 7. An Interactive Training Experience

Participants spoke repeatedly of how they appreciated the interactive format of the training in Second Life. Particular interactive aspects of the training that stood out to participants included teleporting to the stations and following the arrows to move through the training. Participants really enjoyed the activities included in the training; some of those mentioned included the car, the cane and the zip line. One participant commented that due to the interactive nature of the training, he felt as though he were really there, going through the course.

Theme 8. Mixed Experience with Training Videos

Participants had both positive and negative experiences related to the videos included in the training. While participants indicated they were glad there were videos in the training, several noted that the videos didn't load or were blurry. Several participants commented that they enjoyed listening to the amputees on the videos. One participant shared that he liked "sitting" as an avatar watching the videos on the big screen.

3.4 Perceptions of Training Content

Theme 9. Complete and Educational

Participants found the information in the training to be comprehensive. Participants noted that they found the training interesting, and were able to refer to specific examples of information they recalled that they had found useful or interesting. A majority of participants volunteered that they most enjoyed the information about the history of prosthetics.

Theme 10. Best for New Amputees

Participants indicated that they felt the training content was best suited for new amputees. Those who were new amputees expressed appreciated for gaining a better understanding of what to expect. Those who have been amputees for some years spoke of knowing much of the information but finding "reinforcement" in that information.

Theme 11. Positive Outcomes

Participants felt they benefited from the training content. Many noted that they had learned a lot; examples cited included ways to put on a prosthesis, ways to do leg exercises, and how to button a shirt with one hand. A few indicated that the training gave them "a good outlook." Several participants shared that the training gave them an expanded sense of options and possibilities.

Theme 12. A Transformational Experience

Within the category that summarized results pertaining to Perceptions of Training Content, a significant result was that several participants indicated that they found the training in Second Life to be a transformational experience. In referring to the sequence of training stations in SL, one participant commented, "It felt as though I left home and actually took on the course." Many noted that they had applied what they learned in real life. Examples cited included stump care and walking on an uneven surface. A participant noted that following this experience, "I see myself just meeting the challenge without hesitation and resolving any issues by breaking them down. It is easy to be aggressive and without fear in SL." Several noted that participating in the training gave them a sense of connection with other amputees. One participant stated that the training gave him the strength to look at his amputation incision for the first time.

3.5 Perceptions of Training Needs of Friends and Family

Theme 13. Understanding the Challenges of the Amputee

Participants indicated that friends and family need training that would provide a better understanding of the challenges amputees face, including how difficult it can be to function with a prosthetic device and issues of daily life. Friends and families need to understand all the stages a person with limb loss goes through. Participants noted that friends and family need training not only on the content in this training but also on the emotional needs of the amputee. One participant suggested it would be beneficial to have a site on Second Life where friends and family could learn together.

Theme 14. Knowing When and How to Help

A repeated observation of participants was that friends and family need to learn when and how to help the amputee. Participants indicated friends and family need to learn how to be more patient, and how to talk to the amputee. Participants also suggested practical training such as how to help an amputee who falls, or how to help an amputee up the stairs.

4. CONCLUSIONS

In this paper we have presented the results of the qualitative portion of a larger study that compared two methods of accessing a self-management training for amputees: e-learning using Articulate® software and the SL virtual world. The qualitative study consisted of 17 individual interviews in which participants responded to open-ended questions related to their experience of completing the training and the meaning they found in engaging in SL. Interpretative Phenomenological Analysis was selected as the appropriate methodology in order to focus on lived experience from an interpretive and idiographic perspective. Data analysis led to the identification of 14 themes, grouped within 5 major categories. In this paper, we presented five categories of themes which together shared the common superordinate category: Expanded Sense of Possibilities. These possibilities were not limited to the amputees themselves, but included family and friends as well.

Through the vivid words of participants as they described their experiences and shared their perceptions of completing the self-management training, it could be seen that they found SL to be a freeing environment, that they identified with their avatars and found that using the avatar gave them a sense of new possibilities, which led to the training being a transformational experience that impacted them in real life. We close with the following quote of one participant, which captures the spirit of the participants collectively in terms of the broader impacts of their experience of training in SL:

> *I looked at myself and realized I need to get active. That I need to acknowledge that this is not a novelty. It is very real and how am I going to make my life better. What am I going to implement to make my life work. For example, I have my old leg and liners, etc. just sitting around my room. That's not what I do with my other stuff. I need to get it organized. Also on a daily basis I need to not be afraid to walk without thinking that every step might mean I'm going to fall. I look at young people and they can do it. It's a mindset that I am working on adopting for myself as I move forward.*

Acknowledgements: We would like to thank all the participants in this study. This project is supported by the Agency for Healthcare Research and Quality Award # R24HS022021, PI Sandra Winkler, 2013-2017. We dedicate this paper to Al Hall, the PhD student who conducted the interviews as part of his doctoral research. Sadly, Al is no longer with us to witness the results of his work, but we are indebted to him for his contribution.

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Face to face: an interactive facial exercise system for stroke patients with facial weakness

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ABSTRACT

Each year 152,000 people in the UK have a stroke. Almost all have an initial facial weakness. Many resolve in the first few days but it is estimated that 26,000 people experience some kind of long-term paralysis in their face. This may impact on their eating, drinking, speaking, facial expression, saliva management, self-image and confidence. A survey of 107 UK based clinicians found that routine treatment of facial weakness was provision of exercises with a written instruction sheet. The UK National Stroke Clinical Guidelines recommend that patients undertake 45 minutes of therapy per day, but anecdotal evidence suggests that patients have poor adherence to the exercises because they find them boring and there is no feedback to help them see a difference. A multidisciplinary team, which includes patients, researchers and therapists have produced a working prototype system to improve facial weakness. It is called Face to Face and includes a Kinect sensor, a small form PC and a monitor. Patients follow exercises given by a therapist on the screen; the system records and simultaneously gives feedback, with a facial recognition algorithm providing tracking data for each captured frame of the user's face. Results from our small clinical trial indicate that the system is more successful at getting patients to complete their exercises than using a mirror, patients liked it, and they said it had helped improve their facial symmetry. Therapists said Face to Face encouraged patients to exercise daily, they liked the fact that it could be individually programmed and could record how much the patient had exercised. Based on the initial project work and positive outcomes Face to Face aims to help patients practice their facial muscle exercises to speed their recovery, providing direct benefits in terms of costs and time, and offering patients significant improvements.

1. INTRODUCTION

The overall aim of the project was to test an effective, engaging and affordable interactive facial exercise system for use with people with facial weakness following stroke. This is to meet patient and clinical needs and lead to measurable improvements in clinical outcomes (Breedon, 2015, Breedon et al, 2014 & O'Brien, 2014).

Face to Face is a computer based system that enhances and automates the therapy provided by Speech and Language Therapists (SLTs). The system is initially aimed at stroke survivors suffering from facial paralysis, particularly with stroke patients suffering from swallowing and speech problems. The project development team also propose that the system may become a 'platform' system and be adapted and used more widely for a number of conditions and associated facial weakness.

A partnership between Nottingham Trent University, Nottingham CityCare Partnership, University of Nottingham, an industrial partner and service users within the UK have produced a system for use in the home, which uses the Microsoft Kinect games interface and a PC monitor to develop an interactive system to assist in the rehabilitation of patients with facial weakness. The aim is that patients will use this system to complete exercise programmes by copying on-screen exercises, and as they do this the system will monitor and *measure* the patient's face. Members of the University of Nottingham Stroke Research Partnership Group confirm the need for facial paralysis rehabilitation; currently there is a lack of appropriate and affordable alternatives in the market.

The system recognises facial expressions by tracking movement across the face and applying the recognised motion onto an onscreen representation of the user. This tool recognises differences between an undesirable one sided (unilateral) movement and a desired symmetrical movement across both sides of the face. This information is then conveyed via the monitor using the form of a graphical representation of the patients face. Using the representation as both a visual and auditory communicator, the system takes the patient through a series of exercises and indicates the degree of success with the exercise programme. An international patent application for the system was filed in 2015 (PCT/GB2015/053623).

1.1 Patient benefit

A key aspect of the system is the ability to visualise the improvements that the patient is making from repeated exercises. The system is simple to set up, with no need to attach any systems or markers to the face. The user interface permits small bursts of exercises to be performed throughout the day, rather than undertaking one long and tiring session. The overall aim of the initial project study was to test an effective, engaging and affordable interactive facial exercise system for use with people with facial weakness following stroke. This is to meet patient and clinical needs and lead to measurable improvements in clinical outcomes.

The system has the potential to be of benefit to patients by:

1. Improving fidelity in rehabilitative exercises prescribed for facial weakness.
2. Providing immediate feedback to patients on their progress, and in the future could provide a graded exercise programme.
3. Improving patient's facial weakness.
4. Including carers in the rehabilitation process (a Stroke Association recommendation).
5. Assisting patients in meeting the recommended target of 45 minutes daily therapy.
6. Reducing the need for patients to visit hospital for rehabilitation.

1.2 Clinical need

Approximately 16% of people suffering stroke have long lasting facial weakness (Svensson et al, 1992). A combination of physiotherapy, occupational therapy and speech therapy has been proven to be clinically effective in the treatment of those who have suffered facial weakness following a Stroke. However, whereas the National Clinical Guideline for Stroke (Intercollegiate Stroke Working Party, 2012) indicates that patients should receive 45 minutes of therapeutic treatment daily, the majority of patients receive far less than this. The Royal College of Physicians National Sentinel Stroke Clinical Audit (NSSA, 2010) states that only 33% of patients receive 45 minutes or more physiotherapy daily and only 18% of patients receive 45 minutes or more speech and language therapy daily.

It is clear from previous studies, and from involvement with partners at Nottingham University Hospital and the Stroke Association, that there are currently insufficient resources within the NHS to provide the necessary level of therapeutic care post Stroke. The most common rehabilitative exercises prescribed to facial weakness sufferers are either practising motions in front of a mirror or using an instructional DVD. These methods cannot be considered as engaging, due to their lack of feedback and quantifiable progression. Less commonly available is an electrical muscle stimulator designed for facial uses. This machine is made by the NHS electronics departments, and is in short supply, with recipients tending to get a maximum of six weeks to use the system before it is given to the next patient. The machine electrically stimulates the affected muscles to the point that they get exercise through contraction. It is reported to work well in the short term, but owing to short supply and the high price of working machines, along with a lot of training required on the part of the user, it is not currently considered a sustainable solution.

1.3 Initial system concepts

Initial system design concepts were based on the utilisation of the patient's own TV with a 'plug and play' 3D system attached. Over a development period of 18 months the preferred options were discussed and agreed with the patient and public involvement group (PPI), resulting in a PPI informed user interface and physical system design based on the Kinect sensor as shown in Figure 1.

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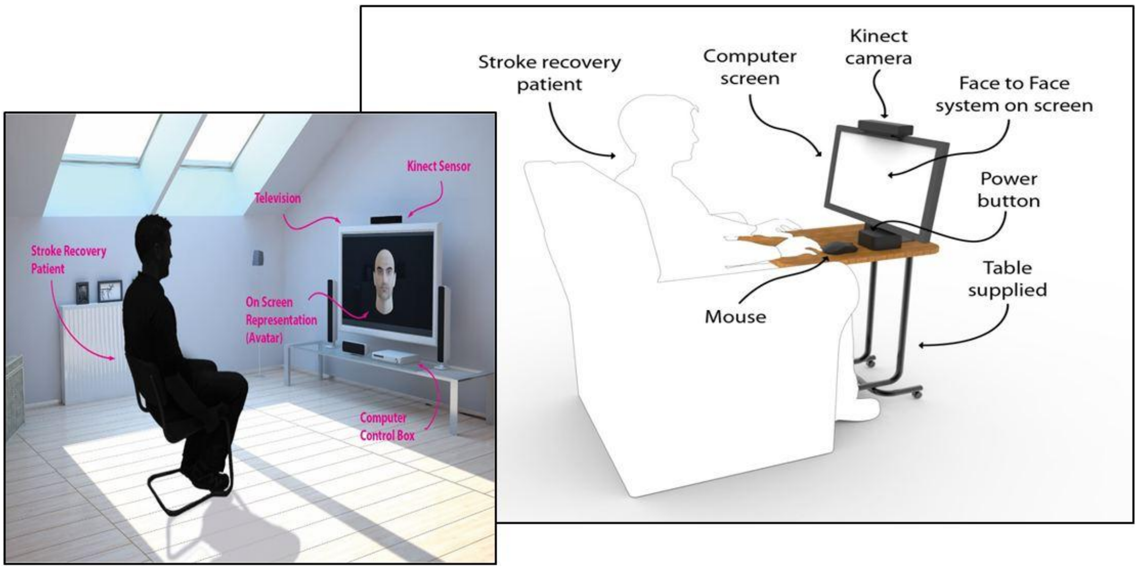

Figure 1. *Initial concept (inset) and PPI informed system design*.

The system that has been developed as a result of this project recognises facial expressions by tracking movement across the face and applying the recognised motion onto an onscreen representation of the user. How the user performs a series of facial exercises is assessed by the system and scored according to how well the user can do each of a defined set of expressions. The therapist is provided with a record of exercises as they were performed. New movements can be introduced automatically, with incrementally achievable goals throughout the week. The system will enable shorter consultations through the presentation of quantified improvement and empower the carer and the stroke survivors to take on some of the role of supervising the performance of the exercises.

It is proposed that the 'home rehabilitation' solution would help offset some of the problems associated with transfer from hospital to home care. The "Moving On" report (Chartered Society of Physiotherapy and Stroke Association, 2010) states that 48% of Stroke survivors believed that community and home-based therapy helped them become less long term reliant on carers.

2. SYSTEM OVERVIEW

Game based technology platforms are now widely used for physical rehabilitation of patients, recognised as a potential motivational tool for rehabilitation. New opportunities in rehabilitation have clearly arisen with emerging technologies of computer games and novel input sensors including 3D cameras. Hossein and Khademi (2014) provided a review on the technical and clinical impact of the Kinect on physical therapy and rehabilitation. Omelina et al (2012) examined serious games for physical rehabilitation and Webster and Celik (2014) provided a detailed review of elderly care and stroke rehabilitation systems utilising the Kinect. As 3D facial image processing for this research project provides clear additional pose mapping functionality, the benefits of processing depth information when compared to 2D vision systems was explored by González-Ortega et al (2014) in relation to Kinect based systems for cognitive rehabilitation exercise monitoring.

Currently the system has been developed utilising pre-existing facial recognition software known as Faceshift (available from www.faceshift.com and now owned by Apple). Image data is acquired from the Kinect and, when a face is detected, a model is generated of the user's face. A profile can be stored for each user by capturing a pre-set series of expression, with an increased level of accuracy obtained by placing markers on a scanned face. This setup routine may be performed typically by a speech and language therapist (SLT), but should only need to be carried out once, following which the user can operate the system independently.

2.1 Pose matching

A short review on image processing was conducted by Samsudin and Sundaraj (2012) for facial paralysis and facial rehabilitation, identifying image processing as being widely utilised but with very limited applications in relation to facial rehabilitation. Further Zhang and Gao (2009) provided a critical review of face recognition techniques and the clear challenges particularly in relation to pose invariant face recognition, whilst Wang et al,

(2015) examined real time movement linked to an evaluation of skeletal pose tracking using the Microsoft Kinect first and second generation hardware.

Clearly various complications in computer vision require an assessment of pose objects in real-time with numerous reliable solutions available for pose estimation utilising feature-based 3D tracking. However difficulties can arise based on the need for fast and robust detection of known objects in view, for example the Kinect sensors used for this project were notably affected by ambient lighting conditions.

For the Face to Face system, once the facial recognition software is set up to track a user's face the facial recognition algorithm provides tracking data for each captured frame of a user's face. The tracking data relates to a number of facial gestures, together with a value associated with each gesture. In Faceshift, 48 channels of raw tracking data are provided per frame, each of which is associated with a number ranging between 0 and 1. The numbers, or scores, represent the strength of deformation on the 48 predefined gestural channels. For example, the gestural channel 'BrowsD_L' measures lowering of the left eyebrow, and 'LipsStretch_L' measures sideways movement of the left corner of the mouth. These numbers do not represent physical units, but are relative scores defined by upper and lower limits of each facial gesture. These scores are then used to analyse how well the user is performing a particular facial expression.

The speech and language therapist (SLT) defines a number of facial expressions, the facial expressions being specific to a user's rehabilitation programme. These facial expressions can each be defined as a combination of facial gestures that can be captured by the facial tracking algorithm, with each facial gesture having an associated target score. The overall aim of an exercise programme setup for a user is to encourage the user to perform the facial expressions and have these analysed and scored by the computer, using the facial recognition algorithm. To do this, a measure of how well the user is performing a particular facial expression needs to be defined. The mathematical space of tracking variables obtained from the facial recognition algorithm is mapped into a target space of facial gestures (or 'poses') for a particular facial expression. For each pose a measure termed a 'pose match strength' may be defined, for example as another number ranging between 0 and 1.

Pose match strength can be computed from the source tracking channels by defining a subset of the source channels as 'pose channels' that influence the pose match strength value for the facial expression being assessed. Source channels that are not included in a particular pose definition can either be ignored or treated as 'wildcards' for the match, for which any value will match. These represent channels that are irrelevant to the facial expression being exercised. As an example, mouth poses typically would not depend on eyebrow positions, resulting in the values for any eyebrow-related channels being discounted in an assessment of a mouth-related pose. Included pose channels may each define a target value or score for the pose, typically over the input range of between 0 and 1). This score is used to calculate an individual channel match value (again between 0 and 1). The range of input source channel values, i.e. from a minimum to a target value, is linearly mapped to an output pose channel match of 0 to 1. Beyond the target value the output pose channel match is capped at 1.

Figure 2 shows a pose tracking value over time, as defined by 14 successive samples, with a pose match peak of 0.8 and a peak value defined at 0.7 based on the development of the pose tracking value. During each 'out of pose' phase (while the system is looking for an 'in pose' event), whenever the instantaneous tracking value reaches a new highest value this 'pose match peak' value is recorded, and the time is recorded. A moving average is then maintained over the 'time since last peak', which will start at the peak and gradually decline as the instantaneous match strength diminishes.

Once a predefined time threshold is reached (which may, for example be around 0.5 seconds, and typically less than one second) without a new peak value being observed, an enter pose event is triggered and the current moving average is stored as a match value for the current 'active' pose. Conversely if a new instantaneous peak value is reached before the time threshold is reached, a new peak value is recorded, the timer is reset, and a new moving average measurement begins. This can happen several times before reaching a stable peak, particularly if the signal is noisy and/or the peak value is relatively low. The partially unsuccessful short-duration peaks before the final successful peak are analogous to 'false horizons' that are due to noise in the signal, whereas the moving average represents an adaptive threshold which continually adjusts to varying user ability and tracking response.

Each pose channel included in the pose definition may be marked as either a goal or a constraint. The output pose match strength is a relative score that can be calculated as the maximum of the set of all computed goal pose channel match values, limited by the minimum of the set of all constraint pose channel match values. This is similar to goal channels acting as logical 'OR' and constraint channels acting as logical 'AND'. The score for each facial gesture may be defined as a ratio of a score for the facial gesture provided by the facial recognition algorithm to the target score for the facial gesture. The score may range between 0 and 1, and be limited to 1 if the ratio exceeds 1.

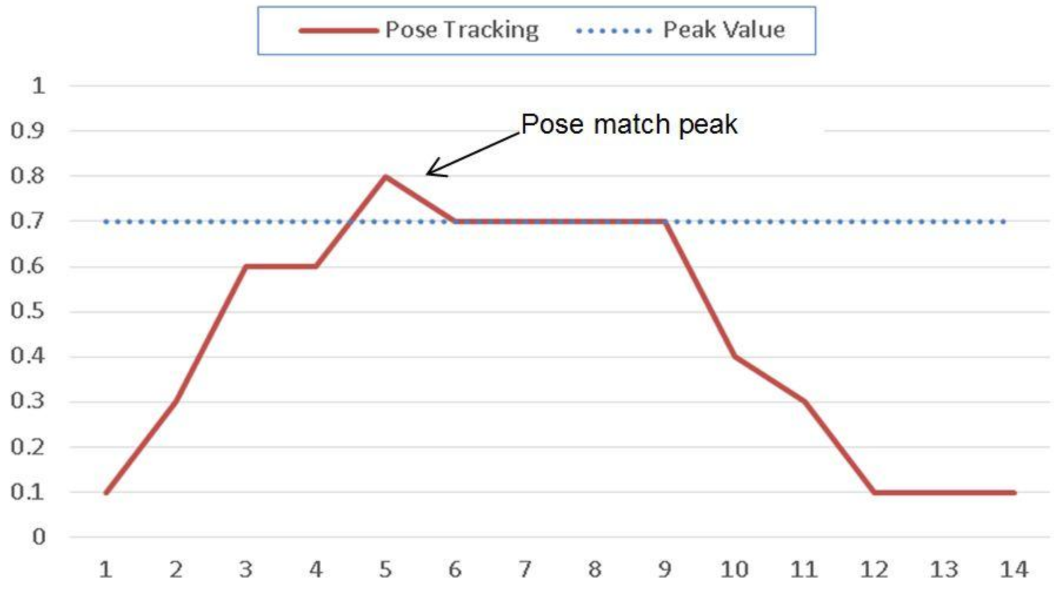

Figure 2. *Pose tracking over time (samples 1 to 14).*

2.2 Step process

Each of the exercise types relies on a predefined series of steps, these steps are illustrated in Figure 3. The process begins with an on-screen instruction phase with an acknowledgement when the number of repetitions has been completed. In between these two phases, the exercise involves looking for a particular target pose at any given time, which may even apply in the case of speed exercises which involve alternating between two poses. When an exercise target pose begins, the state is initially ‘out of pose’ and the system waits for the user to enter the pose. Once in pose, the system waits for the pose match strength to drop below a predetermined threshold value.

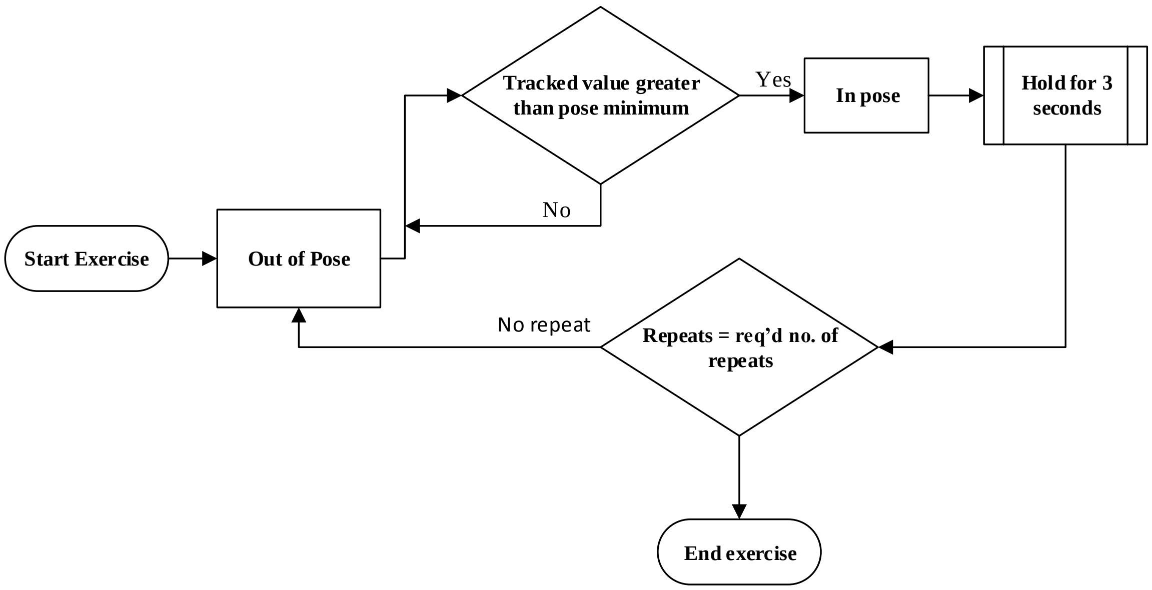

Figure 3. *Exercise steps.*

The events of entering and exiting a current target pose can trigger different responses depending on the exercise type. For example, speed exercises may switch to an alternate pose on exiting a first pose, whereas range exercises tend to set an ‘anti-pose’ during a relax phase which the user must enter (for example open mouth, followed by closed mouth) before returning to the original target pose for the next repetition (open mouth). Once the user is in pose the user is instructed to hold for a set period, and once the set period elapses the process can then repeat if required or complete. The series of steps involved in performing an exercise transforms a continuous range of pose match strengths into a series of discrete states and state change events. The user interface indicates the number of repetitions, which then triggers the next instructional video ("open your mouth..." / "...and relax"). A particular problem, however, arises when considering how to determine when a particular pose has been achieved, i.e. when the state should change from 'out of pose' to 'in pose'. This determination can be made on the basis of a continuous assessment of the score for a facial expression that is the subject of the exercise.

2.3 Pose example

The 'ee' pose may be defined by MouthSmile_L (left) and MouthSmile_R (right) as goal channels, each with a target value of 0.8, defining JawOpen as an inverted constraint channel with a target value of 0.5. The following two conditions then result:

Condition 1:

MouthSmile_L = 0.2 - goal match 0.2/0.8 = 0.25

MouthSmile_R = 0.6 - goal match 0.6/0.8 = 0.75

JawOpen = 0.3 - inverted constraint match = 1 (less than target 0.5, inverted, capped to 1)

Pose match strength = min (max (goal), min (constraint)) = min (0.75, 1) = 0.75

Condition 2:

MouthSmile_L = 0.2 goal match 0.2/0.8 = 0.25

MouthSmile_R = 0.6 - goal match 0.6/0.8 = 0.75

JawOpen = 0.8 inverted constraint match = (1 - 0.8) / (1 - 0.5) = 0.2/0.5 = 0.40

Pose match strength = min (max (goal), min(constraint)) = min (0.75, 0.40) = 0.40

This example could be interpreted as: an 'ee' pose requiring MouthSmile Left OR Right, AND jaw mostly closed. In the second scenario, the pose match strength is reduced to 0.4 because the jaw constraint is infringed, limiting the overall output value. In more general terms, a relative score for each identified facial gesture in a facial expression is calculated as a ratio of the score for each identified facial gesture to the corresponding target score for the facial gesture. The score for the facial expression can be calculated based on a maximum relative score for the facial gestures defining the facial expression. Other combinations of goals and constraints can also be determined, depending on the particular facial expression to be exercised and whether any particular constraints need to be considered. For example, a facial exercise regime may be made up from a set of nine different poses. These may be combined using 9 range exercises with 9 strength exercises and with 3 poses used in pairs in 'fast' and 'slow' versions to make up 6 speed exercises (AB, AC, BC x fast/slow), making a total of 24 exercises to be performed in the exercise regime. A therapist can then make a patient assessment, and simply enable or disable each exercise from this palette of 24 exercises to quickly construct a tailored exercise regime for that user. A screenshot pose is shown in Figure 4 and the patient progress screen in Figure 5.

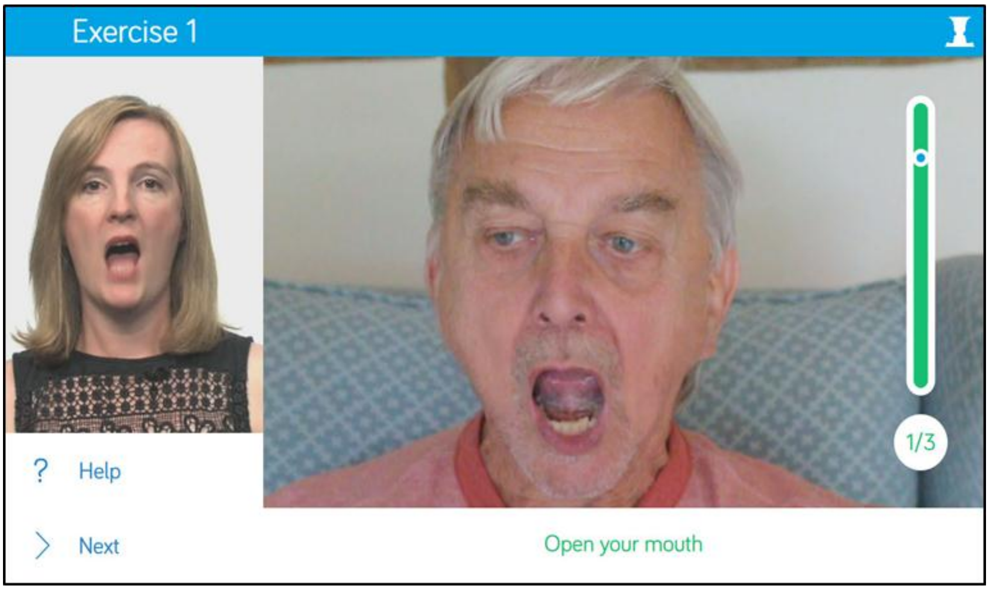

Figure 4. *Exercise pose screenshot with a graphical indication of the user's score (right) and exercise number (bottom right) overlaid on a picture of the user next to an image showing the pose to be performed. The pose indicated by a speech and language therapist (left).*

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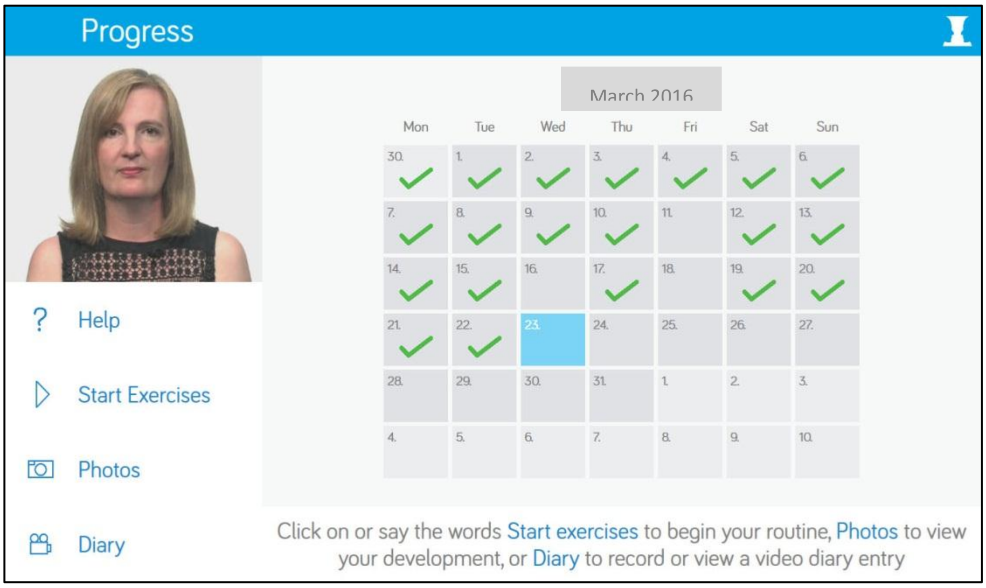

Figure 5. *System diary and progress screen.*

Looking forward, there is a growing number of technologies coming to market that will benefit and enhance this product. Of particular interest is the *new* 3D camera technology launched by Intel. These 3D cameras use the same principles as the Kinect camera but designed to be integrated into phones, tablets and laptops. Another important feature of the Intel cameras is that they have been specially designed to focus on facial recognition and tracking, this will provide an accurate and reliable facial tracking system for us to use. In contrast the Kinect system is designed for full body tracking, although the system can be used to track facial expressions it is not its primary function and therefore limits the effectiveness of the product and requires us to pay for 3rd party software licences.

In current practice, SLTs priorities are in assessing and planning the patient's therapy, and non-professional assistant practitioners (APs) are used on a day-to-day basis with the patient to monitor adherence to the program and assist the patient. We propose to extend the stored usage database to include a record of planned usage regimes for each patient, and to provide a visual comparison of actual usage against the planned regime in the web interface. This approach would allow an AP to interpret the live usage data in the web interface, identifying overuse or underuse of exercises without needing to involve an SLT in the first instance. The web-based interface would still be accessible to SLTs who could perform any further analysis they felt necessary, but they would now also be able to remotely adjust the exercise regime while the device was still in the patient's home. Further development of the product is required and to address other market opportunities, including:

- Improving the user interface to address shortcomings identified in trials and research;
- Improving the compactness and portability of the physical embodiment;
- Strengthening the robustness and functionality of the system (for example in low light conditions);
- Reducing unit cost;
- Allowing for a wider range of exercises, implying a more complex interface requirement to allow SLTs to set up systems for patients.

It is anticipated that this additional functionality would reduce the on going costs of deploying the final system within everyday healthcare practice, by reducing the required time from the SLT.

Acknowledgements: The authors also gratefully acknowledge the invaluable support and contributions to the project from: Ossie Newell MBE, The stroke service (PPI) group, Adam Russell and Paul Watts (both previously based at Nottingham Trent University, UK), Patrick Hall at Maddison and Claire Wragg at NTU. The Face to Face project was funded by the UK National Institute for Health Research Invention for Innovation (NIHR i4i) programme.

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Evaluating automated real time feedback and instructions during computerized mirror therapy for upper limb rehabilitation using augmented reflection technology

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ABSTRACT

The use of Virtual and Augmented Reality (VR/AR) in physical rehabilitation can provide better control, improved user motivation, and flexibility in how therapy is offered. Mirror therapy is a therapeutic intervention that has been shown to be beneficial for upper limb stroke rehabilitation. However it requires, in its clinical application, the constant presence and attention of a skilled therapist who provides instructions. This paper presents an AR mirror therapy system that provides automatic instructions and feedback. A within-subjects design user study with healthy volunteers was conducted to evaluate the usability (System Usability Scale), perceived suitability (Suitability Evaluation Questionnaire for Virtual Rehabilitation Systems), satisfaction (subset of Usability Satisfaction Questionnaire), general experience (Mixed Reality Experience Questionnaire) and participants' performance and preference. We compared two conditions where the system automatically instructed the participants and (i) where the system additionally provided feedback, or (ii) the system did not provide feedback. All participants were able to complete the automated mirror therapy intervention. Participants significantly rated the usability and suitability of the automated intervention as positive. The comparisons between the two conditions on *user experience* and *satisfaction* indicated preferences for the feedback condition; however it was not statistically significant. In the direct comparison between systems, participants showed a strong and significant preference for the feedback condition. A few participants reported a mild level of discomfort attributed to the sitting position, exercises and placement of their hands on the table. With this study, further progress towards an automated system for the provision of mirror therapy was achieved and successfully evaluated with healthy participants. Preparations for clinical evaluations using this automated system with patients suffering from motor impairments after stroke can now commence.

1. INTRODUCTION

Computer mediated visual feedback systems using virtual reality and augmented reality such as Augmented Reflection Technology (ART) show promising potential as part of a rehabilitation program for motor impairments after a stroke, to improve arm function and assist in daily living (Laver, George, Thomas, Deutsch, & Crotty, 2011).

Despite the availability of many protocols for stroke rehabilitation and intervention, today only about 10% of stroke patients recover completely, while 25% will suffer from minor impairments, 40% will experience moderate to severe impairments that require special care, 10% will require care in a nursing home or long term care facility, and 15% will die shortly after (stroke.org, 2015).

An emerging possibility to improve the therapeutic outcomes of stroke rehabilitation is the use of technology such as ART. ART uses computer mediated visual feedback to provide an alternative to traditional therapeutic methods (Hoermann, Hale, Winser, & Regenbrecht, 2012). An ART system consists of two monitors connected to a single computer, with one monitor for the patient and one for the therapist. The patient's hand movements are captured by web camera(s), the captured video is processed and manipulated by software and the results are displayed on the patient screen. This approach allows for a variety of computer mediated therapeutic interventions. ART has been clinically evaluated as part of an upper limb stroke rehabilitation scheme and a specifically tailored protocol for the intervention was established (Hoermann et al., 2015).

This tailored protocol is based on a validated therapeutic intervention called mirror therapy (MT). During MT, a mirror is placed between limbs with the mirror facing the unimpaired side; patients can see a visual overlay of their unimpaired hand at their impaired side. The therapeutic effects of MT are speculated to be due to increased activation in brain areas (e.g. precuneus, posterior cingulate cortex) functionally connected to the stroke affected area in the motor cortex (Mehnert, Brunetti, Steinbrink, Niedeggen, & Dohle, 2013; Michielsen et al., 2011). MT was originally proposed as an intervention to manage phantom limb pain (Ramachandran, Rogers-Ramachandran, & Cobb, 1995). However, its efficacy as a therapeutic intervention for motor rehabilitation after stroke was soon after investigated (Altschuler et al., 1999) and was recently confirmed in a systematic review and meta-analysis (Thieme, Mehrholz, Pohl, Behrens, & Dohle, 2012).

In MT with ART, computer manipulated visualisations of the patient's hand(s) are shown on screen. The unimpaired hand is mirrored to the other side of the screen to give the patients the impression of actually using their impaired hand. Patients are verbally instructed by a therapist to carry out exercises (hand movements) from a predefined category depending on the stage of the therapy. The therapist has to be present to provide verbal instruction and feedback to the patients.

A systematic review to explore the requirements of autonomous training for adults was conducted by Jettkowski, Morkisch, & Dohle (2013). They found that many principles of motor rehabilitation such as intensive and active execution of exercises, relevance of exercises to daily activities, adequate selection of exercises and consideration of the context can be integrated into autonomous training. However, providing feedback during therapy was not achievable without the presence of a therapist. Nevertheless, the use of technology to provide feedback was suggested as a possible solution.

This research project extends the existing ART system with the functionality to: a) automatically generate instructions for the user to carry out therapeutic exercises as prescribed in the MT protocol for ART and b) to provide automatic feedback during the therapy session. The viability of the computer generated instructions to allow unsupervised execution of the therapeutic exercises was evaluated, as well as how automatic real-time feedback affected the exercise execution and user experience.

A user study was conducted with healthy participants. The study combined quantitative and qualitative measures to determine user performance and experience. Validated questionnaires were used alongside a semi-structured interview at the end of the experiment. This research contributes towards current stroke rehabilitation approaches by evaluating the effectiveness of automatic feedback in an autonomous computer mediated therapy scenario. This research will help with the refinement of how computer generated feedback can be used in therapeutic applications, and how the addition of feedback causes a change in user performance and experience. The possibility to provide an enhanced therapeutic experience could lead to higher levels of patient motivation and therefore positively contribute to the efficiency and effectiveness of therapy (Maclean & Pound, 2000). In addition, the findings on the viability of the computer generated instructions can inform the use and development of therapeutic systems for unsupervised autonomous use by patients either at home or in a clinical context.

2. SYSTEM

The system used consisted of three main components: (1) An off-the-shelf webcam with a HD 720p RGB image sensor (Creative Senz3D, Creative Technology Ltd), (2) tailor-made software to process the image data using OpenCV from the webcam and deliver to the application, and lastly (3) the application itself created using Unity3D which provides the environment in which users will interact with and see on screen. In addition, another screen was used by the experimenter to start and stop the application and configure the various settings.

The hardware of the system consisted of a monitor (Dell Widescreen Full-HD 22″ Monitor) mounted on a monitor arm attached to the desk. The arm allows for users to place their hands under the monitor. The webcam was mounted on a stand attached to the monitor arm and was pointed towards the area where users place their hands. The desktop was covered with a blue curtain placed behind the monitor and under the webcam, to be used as part of the background subtraction performed on the camera image data. A detailed description of how the ART system is used can be found in Hoermann et al. (2015).

2.1 Interaction Capture

To display only the hands of a user on screen, background subtraction was performed on each frame of the webcam stream. The colour image was converted from RGB colour space to HSV. Each pixel was checked to ensure that the hue was within a predetermined range which represented the colour blue. If the pixels were within this range, they were set to transparent. This left the pixels which represented the hands, which were set as opaque.

The reason for using the colour blue was because of the contrast it provides to the skin colour. The placement of the blue fabric in the interaction supports the subtraction of everything but the hands.

2.2 Instruction

The system provided instructions by displaying an image of the current exercise on the screen on the same side as the hand (Fig. 1). The pixels in that image that represented the hand were semi-transparent so that the user was still able see their own hand when they overlapped, and all other pixels were completely transparent.

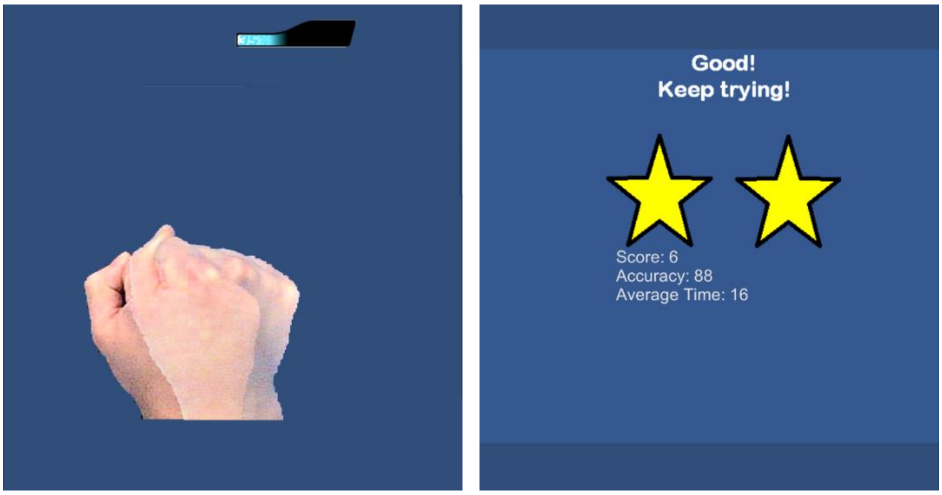

Figure 1. *The half-transparent image of the exercise and the actual hand of the user (left), post-phase feedback (right).*

If the user was able to complete an exercise, another exercise was randomly selected from a list of specific exercises without consecutive repetitions of the same exercise. When a new exercise was displayed, a short audio clip was played to inform the user.

2.3 Evaluation

The current exercise is displayed on screen for a user to follow, while another image of the same exercise is also used by the system for comparison with the images from the video-stream of the actual user's hand. This comparison image is exactly the same as the displayed image except that the transparent pixels are set to black. The system then performs a count of the non-black pixels of the image, which gives a quantitative value for how much space the exercise occupies. This value is referred to as the maximum accuracy for that exercise. When the system performs the background segmentation of the camera data, it also checks the pixels against the corresponding pixels of the comparison image. If this check finds that there are pixels in the camera data that are not empty and also pixels in the image that are not empty, it then assumes that a user has their hand in an area where the exercise is being displayed.

When pixels are found where expected then an accuracy score is incremented, and if non empty pixels are found in the camera data where there are empty pixels, the score is decremented. This approximates how well a user is matching the exercise. The current accuracy score is constantly updated, and then calculated to determine the percentage it is of the total. This percentage is used as the input for the real-time feedback bar (Figure 1, left, right upper corner).

The evaluation of an exercise is done in two steps: first the accuracy score must be above the pre-set threshold, and second the user must maintain this accuracy above the threshold for a pre-set time. If at any point the accuracy drops below the threshold, then the hold time timer is reset and will start once the threshold is reached again. The threshold and hold time are read in from an eXtensible Markup Language (XML) file at system start and can be changed to a custom value to meet required performance. Data is automatically saved into an XML file for each user. The threshold value used for the user study was 80% and the hold time 3 seconds. This means a user must maintain a hand shape at 80% or above similarity to the reference image for 3 consecutive seconds to progress to the next exercise.

2.4 Feedback

The feedback bar (Fig 1, left image, upper right corner) displays the accuracy score in real-time, and states the percentage currently achieved. When an exercise is completed, this accuracy score is saved into the user's XML file, along with the time taken to complete the exercise as well as the exercise ID.

When a phase is completed, the performance information is used to evaluate user performance. The current evaluation method is based on the average accuracy score, which will fit into one of three levels, each indicating an increasing level. The levels are calculated by: 100 minus threshold divided by three. The chosen feedback is then displayed on the screen, on the same side of the screen where the hand is displayed. There is a different feedback screen for each of the three levels, each displaying the number of stars to represent the feedback level achieved and a motivational message. Additionally, performance data from the phase is displayed, showing the score: number of completed exercises, average accuracy, and average completion time. The threshold value used in the experiment is 80, hence an average accuracy of 80 to 86.7 would result in one-star feedback, 86.7 to 93.3 in two stars and above 93.3 in three stars.

3. METHOD

3.1 Participants

Twenty-eight participants were recruited from the University of Otago and Dunedin area. The sample consisted of 20 males and 8 females working in a range of disciplines, between the ages of 21 and 62 years with an average age of 33.79 (*SD* = 12.96). All participants reported to have normal vision and no impairments that could affect their performance during the experiment. Twenty-four participants were right-handed, two left handed and two ambidextrous as measured with the Edinburgh Handedness Inventory (Oldfield, 1971). All participants provided written informed consent and received a chocolate bar as compensation for their time.

3.2 Measures

The experience questionnaire consisted of questions taken from a Mixed Reality Experience questionnaire (Regenbrecht, Botella, Banos, & Schubert, 2013), and was filled out six times, once after each phase was completed. The questions asked participants to rate the ease of performing the exercises, their performance, performance satisfaction, motivation, concentration, and enjoyment. The rating-scale ranged from 0 to 10.

After each condition, participants completed a satisfaction questionnaire, which was a subset (questions 1, 2, 3, 4, 6, 7, 10, 11, 16, and 17) of an IBM Usability Satisfaction Questionnaire (Lewis, 1995). This questionnaire comprised of ten questions on a rating-scale of 1 to 9, on how participants felt about the system while performing the task and the task itself.

Once both conditions had been completed, three different questionnaires were used. The first was a suitability questionnaire containing fourteen questions specifically related to virtual rehabilitation systems (Gil-Gomez, Manzano-Hernandez, Albiol-Perez, & Aula-Valero, 2013). The response-scale was increased from the original 5-point scale to a scale ranging from −5 to 5. The second questionnaire was a usability questionnaire to evaluate the perceived usability (Brooke, 1996). The final questionnaire contained four self-created questions asking participants to pick between each condition on a scale of −2 to 2 for their overall preference, ease of use, motivation, and concentration.

3.3 Design

The experiment used a within-subject design, with the 28 participants pre-randomised and counter-balanced for the feedback and non-feedback conditions, and for the hand used in the experiment. The hand used in the experiment was randomly predetermined and hand dominance was not taken into account but was recorded as part of the demographic questionnaire. The independent variable was "feedback" with levels (i) system will give feedback and (ii) no feedback is provided by the system. In both conditions the instructions were provided automatically by the system. The dependent variables were participant satisfaction, motivation, enjoyment, concentration, and perceived usability. The performance data collected was the exercise execution time, exercise accuracy, and score.

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3.4 Procedure

Experiments were conducted in a controlled lab environment to reduce unnecessary distraction for the participants. Two conditions were evaluated: MT with automated instruction and feedback, and MT with automated instruction but without feedback.

Upon arrival, participants were greeted and given an information sheet detailing the experiment and what they should expect. After reading this, they were presented with a consent form to give their formal written consent. Participants were asked to complete a demographic questionnaire once they had consented to taking part in the experiment.

Before starting with the conditions, an initial setup step was required. This involved the experimenter verbally guiding the participant through the exercises and using the ART system to capture a photo of the participant's hand for each exercise. The 16 hand movements used were the same as used in a previous study (Hoermann et al., 2015) and were based on the Mirror Therapy Manual by Morkisch & Dohle (2015). During the experiment, the ART system would use these images to display the current exercise to the participant and perform a comparison of that image to the participant's hand movements. Some image processing was applied to the images to ensure they met the requirements expected of the system. The images were then loaded into the designated folders for the system to use.

Once the setup was complete, participants were asked to place their hands under the screen and instructed on what to expect from the system. Then, the first pre-selected condition with their pre-determined hand was initiated. Each condition comprised of three two-minute phases. The participant's task was to perform the hand exercise shown on screen and to try to complete as many exercises as they could within each of the two-minute phases. The instructions given to the participant were that they should move their hand to best match the displayed exercise and maintain their hand position in place. The system would then evaluate and progress the exercises automatically. Before starting their first condition, the participants were told that the instruction and evaluation would be the same for both conditions, but in one condition there would be feedback based on their performance. All exercises were carried out by showing a mirrored display of the hand on the other side of the screen.

After each two-minute phase, participants completed a user experience questionnaire. After completing the first condition (three two-minute phases), they filled out the satisfaction questionnaire. When both conditions had been completed, participants completed the suitability, usability, and final comparison questionnaires. After that, participants were thanked for their time and rewarded with a chocolate bar.

3.5 Statistical Analysis

Post-phase feedback data from the three phases with feedback was compared to the data from the three phases without feedback. A two-tailed paired-sample t-test was used to compare the performance of participants between the two conditions. A Related-Samples Wilcoxon Signed Rank Test was used to compare the data from the two satisfaction questionnaires completed after each condition. A One-Sample Wilcoxon Signed Rank Test on the medians of the scales with their neutral midpoints was used. Where indicated, values for negatively worded questions were inverted. Analyses for parametric tests were carried out with Microsoft Excel 2013, and non-parametric tests were conducted in SPSS 22.0.0.2. For all analyses, p-values below .05 were considered as statistically significant.

4. RESULTS & DISCUSSION

4.1 Suitability

The results of the suitability evaluation questionnaire (SEQ) were statistically significant ($p < .001$) with the averages of all questions above the neutral midpoint "0", showing that overall, participants perceived the system as suitable (Fig. 2 left). The ratings of negatively phrased questions Q7–Q10 and Q12 were inverted.

The first seven questions of the SEQ measured enjoyment (Q1), sense of being in the system (Q2), feeling of success (Q3), control (Q4), virtual environment realism (Q5), system information clarity (Q6), and general discomfort (Q7). The high ratings obtained indicated that overall participants enjoyed their experience with the system. However, Q7 had a reasonably low value, indicating that overall participants did not experience a high level of comfort while using the system.

The results obtained for questions Q8–Q10, related to the issues frequently associated with virtual rehabilitation systems, show that participants on average experienced no serious adverse effects such as dizziness (Q8), eye discomfort (Q9) or confusion (Q10). Out of these three questions, Q10 which asked whether a participant felt confused or disorientated had the lowest average value. This was an expected result as many of the participants were initially confused by the mirroring of their hand.

Q11 asked participants whether they believed that the system would be useful for rehabilitation. Although participants may not have knowledge on the field of rehabilitation, this question could still indicate opinions on the suitability of the system. The results were uniformly high and suggested that participants believe the system would be helpful for rehabilitation.

Questions Q12 and Q13 were related to the perceived difficulty. Q12 was the difficulty of the task, which here had a value close to zero. Therefore, the difficulty of the tasks performed by the participants appeared to be neither too difficult nor too easy. As part of the task creation, we would not want to make the task too easy or too difficult. Ideally, the task should feel achievable, engaging, and challenging. Q13 evaluated the perceived difficulty related with the physical interface used in the system and was again positively rated; this was expected as our system only required a participant to move their hands.

Q14 was an open ended question that participants could use to report if there was anything during the experiment that made them feel uncomfortable. Eight participants (28.57%) indicated that they felt uncomfortable in some way when using the system. The written responses included participants feeling uncomfortable sitting so close to the screen, their unused hand feeling sore from holding it still, and specific exercises were causing some soreness.

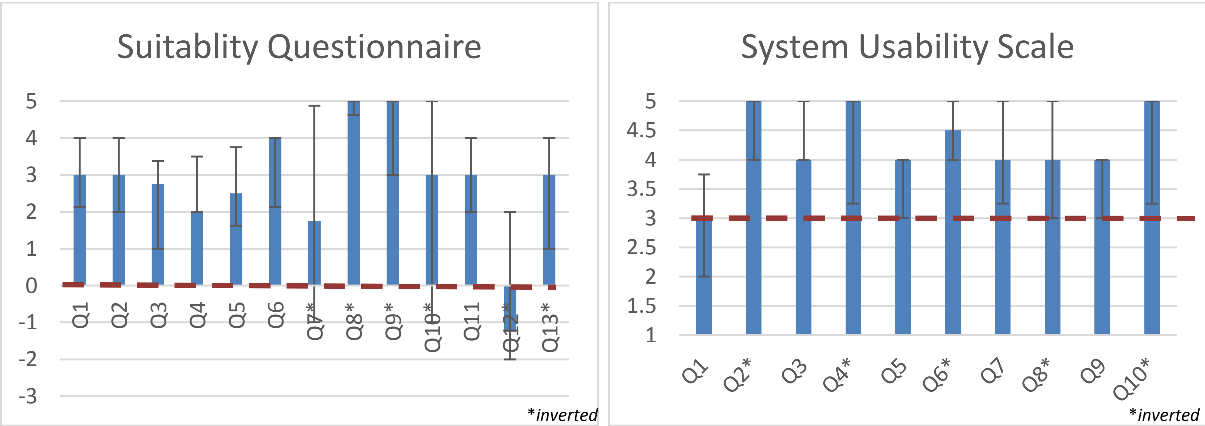

Figure 2. *Suitability Evaluation Questionnaire (left), System Usability Scale (right) (Median and IQR bars).*

4.2 Usability

The results of the usability questionnaire were significantly positive ($p < .001$) with a mean rating of 4, clearly above the neutral midpoint (Fig 2, right). Note that the ratings of negatively phrased questions (Q2, Q4, Q6, Q8 & Q10) were inverted. The SUS score, calculated using the method proposed by the author of the scale, was 75/100. This was above the pooled average of 68 calculated from more than 3,500 prior applications of the SUS and suggest that participants thought the system has good appropriateness for its purpose, although no strong clinical implications can be made as we conducted the study with healthy participants (Brooke, 2013).

Q1 asked how frequently the participant would like to use the system. As the participants were healthy, it was not likely that they would expect to use a rehabilitation system, thus values near the midpoint were not of concern. Participants uniformly rated the complexity of the system (Q2) positively, meaning that the majority of the participants found the system to not be unnecessarily complex. Similarly, participants indicated that the system was not cumbersome (Q8). The system's ease of use (Q3) was also highly rated. The need for a technical person to be able to use the system (Q4) was rated low (i.e. high inverted values), suggesting that overall, participants felt they would be able to use the system on their own. The integration of functions (Q5) was above midpoint, and the inconsistency of the system (Q6) was also positively rated. The learnability of the system was explored in questions Q7 and Q10. Regarding the learnability for other people (Q7), participants indicated that other people would learn to use the system very quickly. For personal learnability (Q10), participants reported similarly high values, suggesting they believed that they did not need to learn a lot before using the system. Participant confidence when using the system (Q9) was also above the neutral midpoint.

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4.3 *Satisfaction (post-condition)*

The satisfaction questionnaire was completed twice, once after the feedback condition and once after the non-feedback condition. The results (Fig. 3) for both conditions show that participants were very satisfied, with medians clearly above midpoint ($p < .001$). The differences between the two conditions (feedback: *Median*=7.25, *IQR*=1; no-feedback: *Median*=7, *IQR*=2) however did not reach significance ($p = .071$).

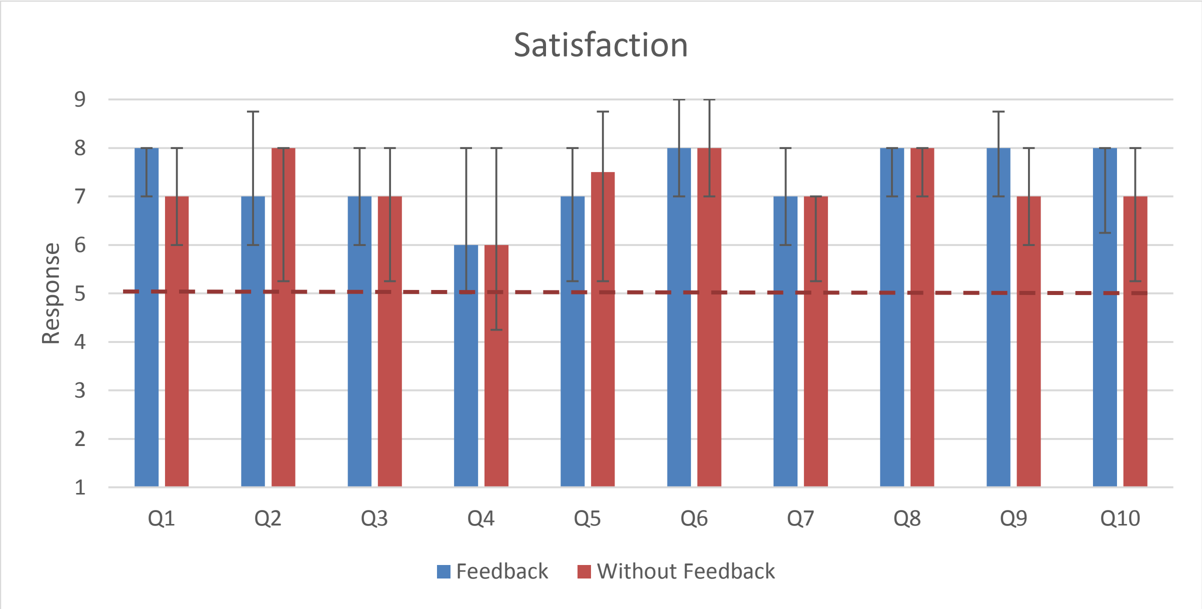

Figure 3. *Satisfaction (Median with IQR bars) and redline to highlight neutral midpoint.*

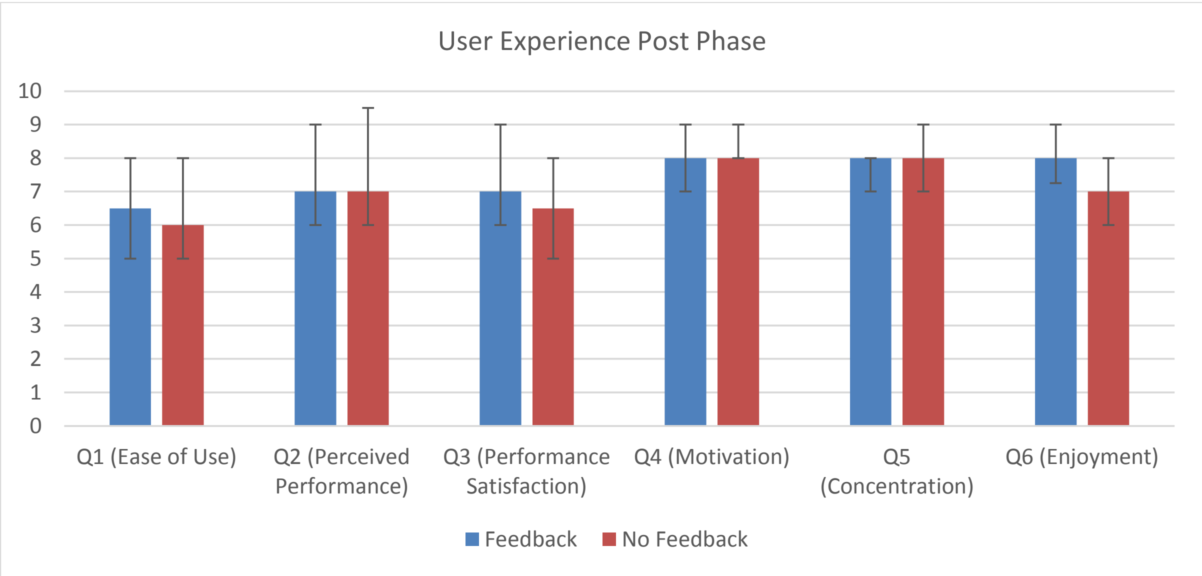

Figure 4. *Average user experience across three measurements for each condition (Median and IQR bars).*

4.4 *Performance*

Analyses of the performance data did not reveal any significant difference between the feedback and non-feedback conditions, across all three phase. The differences in the amount of performed exercises per phase (no-feedback: *M*=8.1, *SD*=4.69; feedback: *M*=8.11, *SD*=4.77) ($p = .38$), the accuracy of the execution (no-feedback: *M*=88.46, *SD*=3.83; feedback: *M*=88.02, *SD*=4.98) ($p = .35$) and the average time required per exercise (no-feedback: *M*=8.58, *SD*=8.12; feedback: *M*=8.50, *SD*=7.18) ($p = .10$) were not statistically significant.

All participants were able to complete at least one exercise in one of the three phases per session. At 11 instances (6.5%), 6 times in one of the three phases during the first session and 5 times in the second session, a participant finished a phase without successfully completing at least one exercise per phase.

4.5 User Experience (post phase)

Levels of user experience were measured after each phase, a total of 6 times, 3 times after phases with feedback and 3 times after phases without feedback. The difference of the overall median of the 6 questions' median was not statistically significant (p = .289) with differences for Q1 (p = .172), Q2 (p = .395), Q3 (p = .930), Q4 (p = .430), Q5 (p = .171) and Q6 (p = .172) all not significant.

4.6 Final Comparison

The final questionnaire asked participants to directly compare the two conditions on a five-point scale with the feedback condition on the left side of the scale ("−2") and the no-feedback condition on the right side ("+2"). Across all four questions, the data were significantly in favour of ART with feedback (*Median*=−1.5, *IQR*=2) (p = .002). The data for the individual question Q1 (general preference) indicated that participants preferred using the system with feedback (*Median*=−2, *IQR*=1.75) ($p < .001$). The results for Q3 (motivation) also showed that participants felt more motivated with feedback (*Median*=−2, *IQR*=2) (p = .002). The ease of use (Q2) was also perceived to be better in the feedback condition (*Median*=−2, *IQR*=2) (p = .001). Q4 (ability to concentrate) was also significant (*Median*=0, *IQR*=3), although not as highly as the other questions (p = .034).

5. CONCLUSION

In this study, we have shown that automated mirror therapy with the ART can be performed with healthy participants and that it is perceived as usable and suitable for rehabilitation by healthy non-clinical participants. We evaluated two versions of the system where we either provided feedback or did not, in addition to giving instructions for the exercises.

Although we could not find a statistical difference on the satisfaction and general user experience between the two conditions, the data indicates that enjoyment was higher in the condition with feedback. When participants had to directly compare the two conditions, strong and significant preferences for the feedback conditions were found.

As part of the suitability questionnaire and when queried informally after the experiment session, some participants reported that they experienced discomfort due to their seated position when using the system. This is already an identified area in which further refinement is required, and is not just specific to the version of the ART system presented here. The discomfort specific to this version of ART is the angle in which participants were required to place their hands to align with the on screen image. Some participants found that they had to place themselves at an unnatural position that was sometimes difficult to achieve or hold still for a prolonged time. Possible use with a patient population could be limited due to the identified problems with seating and hand positioning and improving this will be a focus for future development of the ART system.

The number of times a participant was not able to complete an exercise per phase was low, however it provides some room for improvement especially to ensure a smooth experience for a clinical population. For example, the system could switch to a new exercise or lower the required accuracy when a user is not able to accurately perform an exercise for an extended time. With this study, further progress towards an automated system for the provision of mirror therapy was achieved and preparations for clinical evaluations using this system with stroke patients can now be initiated.

Acknowledgements: The authors thank all participants who took part in this study and Prof Holger Regenbrecht for providing support, feedback and encouragement throughout the period. We also thank Dr Wendy Powell, Dr Vaughan Powell and other experts in the field for their valuable feedback during the developmental phase of the feedback system. This study was part of the dissertation work of Jack Pinches supervised by Dr Simon Hoermann. This study was approved by the University of Otago Ethics Committee.

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Augmented feedback approach to double-leg squat training for patients with knee osteoarthritis: a preliminary study

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ABSTRACT

The aim of this preliminary study was to explore the effects of two types of augmented feedback on the strategy used by healthy participants and patients with knee osteoarthritis (OA) to perform a double-leg squat. Seven patients with knee OA and seven healthy participants performed three sets of eight double-leg squats: one without feedback, one with real-time kinematic feedback and one with real-time kinetic feedback. Kinematic and kinetic outcome measures (peak knee flexion angle, peak knee extensor moment, and symmetry of the support knee moment between the injured and non-injured knees) demonstrate the potential influence of real-time kinetic feedback on the motor strategy used to perform a double-leg squat in both groups. This feedback could be used to develop more efficient and effective motor strategies for squatting in patients with knee OA and further evaluation is warranted.

1. INTRODUCTION

Knee osteoarthritis (OA) is the most common heterogeneous joint disease. Musculoskeletal pain associated with knee OA can hamper the performance of daily living activities and influence wellbeing (NICE guidelines, 2014, Zhang and Jordan, 2010). Physical performance of daily living activities is an important indicator of the impact of knee OA and resulting pain on individuals' quality of life (Blagojevic *et al.*, 2010, Chacón *et al.*, 2004, NICE guidelines, 2014). There are currently no known treatments to slow the progression of OA; however, physiotherapy is one approach used to improve management of the condition (Bennell *et al.*, 2016, Bennell *et al.*, 2014, Page *et al.*, 2011, Tanaka *et al.*, 2016).

Neuromuscular physiotherapy typically includes physical exercise programmes focusing on strengthening, improving and maintaining aptitude for controlling and regulating postural stability, balance, and muscular strength (Lange et al., 2008), and can improve mobility and strength in patients with knee OA. The exercise programmes require interaction between neural systems and musculoskeletal systems to generate forces to accomplish body movements (Shumway-Cook and Woollacott, 1995, Woollacott and Shumway-Cook, 2005).

Innovative physiotherapy tools are needed to improve physical exercise adherence in individuals with OA and should focus on enhancing self-efficacy and enjoyment. Interventions that consider self-efficacy, maintaining motivation and engagement may successfully achieve functional improvements in patients with OA, who often engage and adhere less in physical activity than non-diseased populations (Bandur, 1997, Vermeire *et al.*, 2001). A possible innovative approach to guide physical exercise performance through feedback and increase patients' engagement is the inclusion of virtual reality into physical exercises (Gokeler *et al.*, 2014, Holden, 2005, Rizzo and Kim, 2005). Virtual reality is a technology that allows a user to interact with a computer-simulated environment, be it real or imagined (Burdea and Coiffet, 2003). Using this technology, we have explored the feasibility of providing in-house-developed real-time targeted feedback of kinetic performance during squatting in game context (Al-Amri et al., 2013) .

Considering the importance of implementing a real-time feedback system in a clinical setting, we have developed our targeted feedback application in conjunction with a clinical team. The application is being developed to use simple kinetic data that can be obtained from affordable and simple equipment that is marketed for entertainment purposes, such as the commercial Nintendo Wii balance board (Deutsch et al., 2011, Park and Lee, 2014). We are developing the application for the double-leg squat, as this is commonly used in clinical settings to assess and strengthen muscles around the knee (Escamilla, 2001).

As part of the development process, we are conducting research to understand the influence of two types of feedback (kinematic and kinetic) on the biomechanics of the double-legged squat. The kinematic feedback comprises a stick figure, which represents the subject, being presented on a screen in front of the subject, enabling the subject to view their movement. The kinetic feedback is presented in the context of a game, and requires subjects to focus on the effects of their movements by adjusting the net centre of pressure (COPnet) under their feet to match a target provided on the screen in front of them. The overall aim of this work is to make a preliminary assessment of the effects of an in-house-developed real-time targeted feedback application on the kinetics of a double-leg squat in patients with knee OA. The long-term aim of this research is to determine whether an augmented, real-time, targeted biofeedback approach can aid patients with knee OA by facilitating an effective motor learning strategy and improving self-efficacy.

2. METHOD

2.1 Participant Recruitment

The South East Wales Local Research Ethics Committee approved this research. Inclusion criteria for knee OA patients were: a consultant's diagnosis of knee OA both clinically and radiographically, aged between 18 and 75 years, no previous musculoskeletal surgery in the past 12 months and no other pathologies that affect their movements, no evidence of photosensitive epilepsy, and able to follow simple instructions. Inclusion criteria for healthy participants were: aged between 18 and 75 years and no conditions that affect their movement. Patients were recruited from patients attending physiotherapy clinics.

2.2 Apparatus

The experimental set up compromised the Cardiff Gait Real-time Analysis Interactive Lab system (Figure 1, GRAIL, Motek Medical, Amsterdam, The Netherlands), which consists of an instrumented split-belt treadmill, a 12-camera Vicon MX optical infrared tracking system (Oxford Metrics, Oxford, UK) and synchronised 3D environments that were developed using Google Sketchup (version 8.0, Google, USA). D-Flow software (version 3.20.1, Motek Medical, the Netherlands) was used in the development of the feedback applications and their implementation on the GRAIL system.

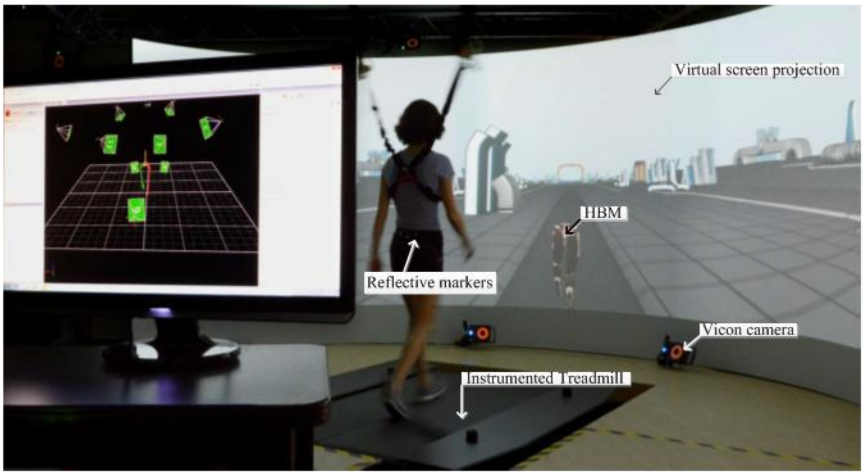


Figure 1. *Cardiff Gait Real-time Analysis Interactive Lab.*

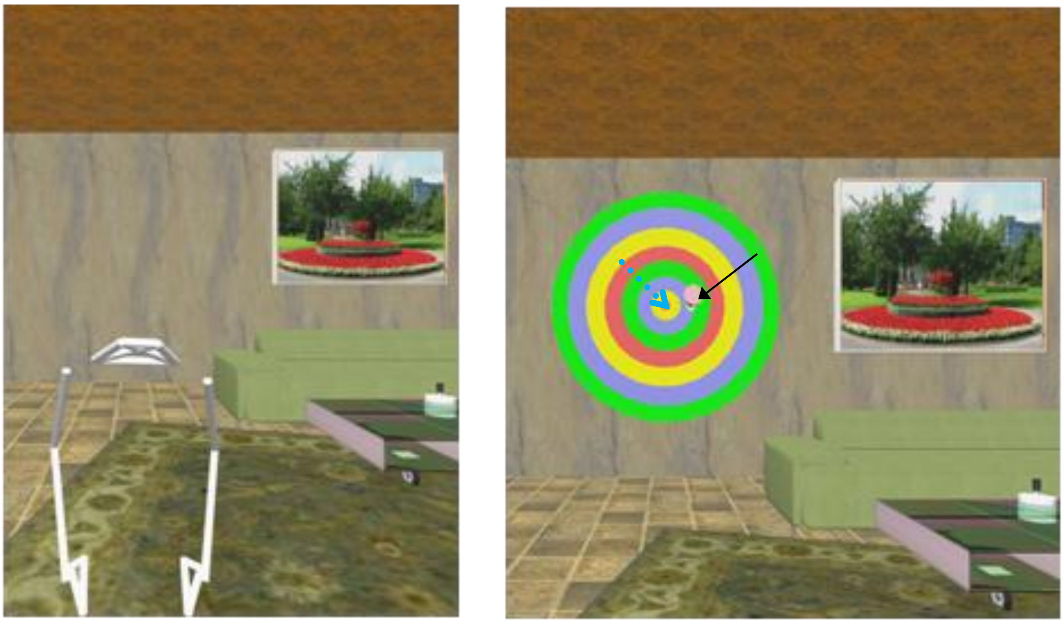
2.3 Procedure

The investigation was carried out in the Research Centre for Clinical Kinesiology at Cardiff University. On arrival, participants were oriented to the laboratory and the study procedures, and consented to the study protocol if they were happy to participate. Demographic, anthropometric (including height and mass) and relevant clinical information (including condition history and any other related medical conditions that may affect knee OA) were then obtained via questionnaire and interview. Patients with knee OA completed the Oxford Knee Score, a validated, knee-specific instrument designed to gather opinion about their knee and associated problems, and all participants completed the Tegner Activity Scale form (Tegner and Lysholm, 1985), a validated measure of activity level. Forty-seven reflective markers were placed on anatomical landmarks using the Motek Human Body Model full-body marker set (Motek Medical, the Netherlands).

Each participant performed eight continuous double-leg squats at their comfortable speed and to a comfortable depth under three conditions whilst they were standing on a stationary instrumented treadmill. The first condition was without feedback, the second condition was with kinematic feedback (a real-time stick-figure of the lower limbs presented in a virtual living room; see Figure 2A), and the third condition was with kinetic feedback (net centre of pressure [COPnet] presented as a virtual object on a virtual arrow mat; see Figure 2B). For the kinetic feedback condition, participants were instructed to keep the virtual object as close as possible to the centre of the virtual arrow mat. COP data were obtained through force plates embedded within the stationary treadmill (Forcelink, Culemborg, the Netherlands) and COPnet was calculated in the anterior/posterior (A/P) and medial/lateral (M/L) directions within Motek D-Flow software (version 3.20.1) using equation (1) (Winter et al., 1998). Initial COPnet was computed whilst participants were standing with a body weight evenly distributed across the left and right feet, and was used to calibrate the virtual object.

$$COPnet = COP_l \frac{R_l}{R_l + R_r} + COP_r \frac{R_r}{R_l + R_r} \tag{1}$$

where $COPnet$: net of centre of pressure; COP_l : left centre of pressure; COP_r: right centre of pressure; R_l: left vertical reaction force; and R_r : right vertical reaction force.



(A) (B)

Figure 2. *A screenshot of the virtual room during the kinematic feedback condition (A) and the kinetic feedback condition (B). In B the blue arrow refers to the target position (where the symmetry support moment is 100%) and the black arrow refers to the virtual object that driven by the actual symmetry support moment.*

2.4 Data Analysis and Processing

Joint and segment angles and moments were calculated using the Motek Human Body Model within D-Flow software (version 3.20.1). The following outcome measures were calculated using Matlab R2015b (Mathworks Inc. USA): peak knee flexion angle, peak knee extensor moment, symmetry of the support knee moment between the injured and non-injured knees (knee OA patients) or between the dominant and non-dominant knees (healthy participants), and total symmetry of the support moment between injured/dominant and non-injured/non-dominant legs. The symmetry support moment (%SYSM) was calculated using equation (2) (Winter, 1990).

$$\%SYSM = \frac{2 * \text{Left Moment}}{\text{Left Moment} + \text{Right Moment}} * 100 \qquad (2)$$

As this is an exploratory study with a small sample size we did not undertake any statistical tests within or between groups. Descriptive analysis of all outcome measures and demographic data was performed using Microsoft Excel 2013 (Microsoft, USA).

3. RESULTS

Seven knee OA patients (gender: four males, three females, height: 171.5 ± 7.2 cm, mass: 87.5 ± 17.2 kg, age: 52.1 ± 10.6 years) were compared to seven healthy volunteers (gender: two males, five females, height: 169.4 ± 8.3 cm, mass: 73.1 ± 15.3 kg, age: 45.0 ± 12.4 years). Details of the participants are summarised in Table 1.

Table 1. *Participant characteristics. Data are means ± standard deviation. OA, osteoarthritis; CONT, healthy control participants; OKS, Oxford Knee Score; Tegner, Tegner Activity Scale; BMI, body mass index.*

	Age (years)	Height (cm)	Mass (kg)	BMI	OKS	Tegner
Knee OA	52.1 ± 10.6	171.5 ± 7.2	87.5 ± 17.2	29.6 ± 3.8	35 ± 5.1	3.7 ± 2.3
CONT	45 ± 12.4	169.4 ± 8.3	73.1 ± 15.3	25.4 ± 4.1	N/A	6.6 ± 1.4

3.1 Knee Flexion Angle

Figure 3 shows the average peak knee flexion angle for each knee across conditions and groups. The difference between groups in the absence of feedback, with kinematic feedback (stick figure) and with kinetic feedback (COPnet target) was 14^o, 15^o and 10^o, respectively. The greatest variability occurred in the kinetic feedback condition, and was at least 2^o higher compared to the first and second conditions across groups. The difference in average peak knee flexion angle between the injured/non-dominant leg and healthy/dominant leg was less than 2^o in all conditions.

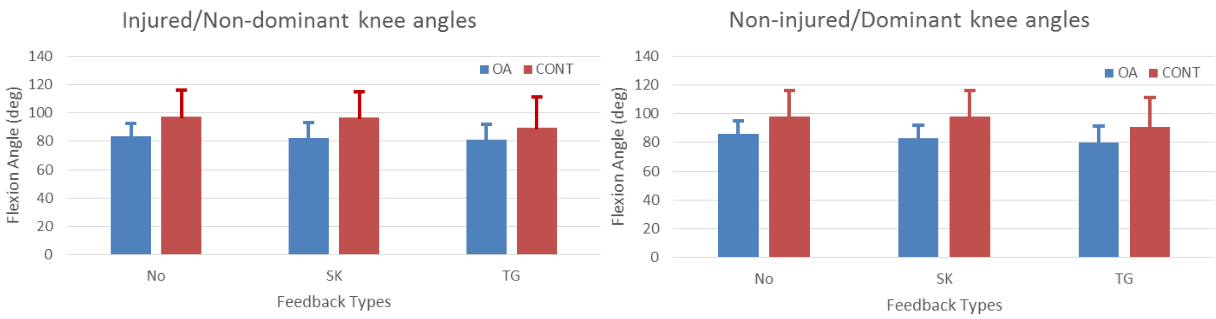


Figure 3. *Average peak knee flexion angle. NO, no feedback; SK, kinematic feedback (stick-figure); TG, kinetic feedback (COPnet target).*

3.2 Knee Extension Moment

In patients with knee OA, the peak knee extensor moment in the non-injured knee was 0.49 Nm/kg.m with no feedback, 0.47 Nm/kg.m with kinematic feedback and 0.45 Nm/kg.m with kinetic feedback (Figure 4). In healthy participants, the peak knee extensor moment in the dominant knee was 0.45 Nm/kg.m with no feedback and with kinetic feedback and 0.43 Nm/kg.m with kinematic feedback, and in the non-dominant knee was at least 0.02 Nm/kg.m higher in with kinematic feedback than with no feedback (Figure 4).

3.3 Support Moment

In both groups, SYSM was closest to 100% in the kinetic feedback condition. In patients with knee OA, SYSM was higher in the kinematic feedback than in the no feedback condition (93.8%; Figure 5). This was accompanied by a reduction of at least 1% in the contribution of the injured knee to the total SYSM. However, in healthy participants, SYSM was 104.4% with no feedback and 96.5% with kinematic feedback, which was accompanied by an increase of 4% in the contribution of the dominant knee to the total SYSM (Figure 5).

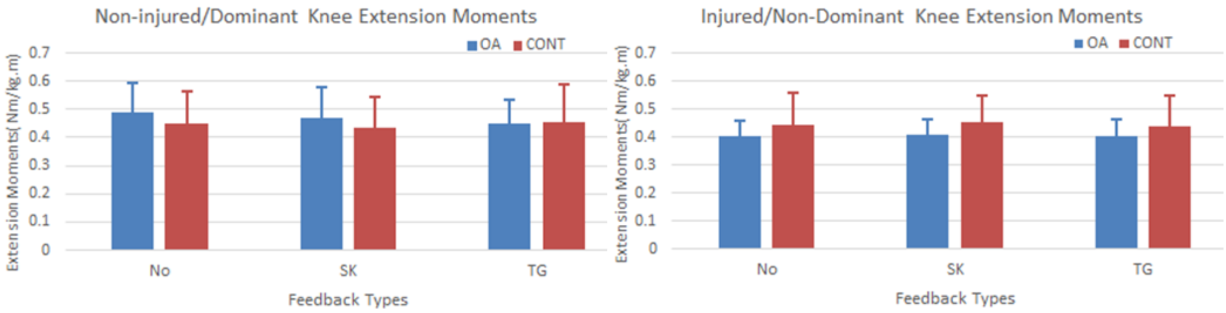


Figure 4. *Peak knee extensor moment. Data are the mean of all subjects. Error bars represent standard deviation. NO, no feedback; SK, kinematic feedback (stick-figure); TG, kinetic feedback (COPnet target).*

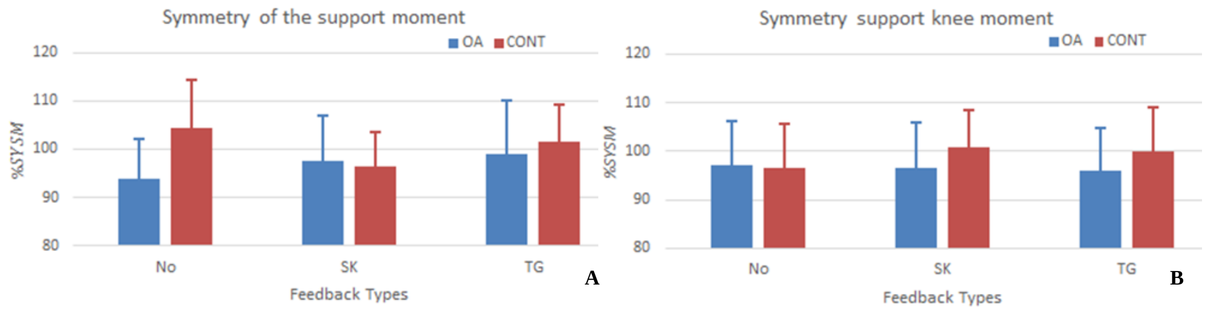


Figure 5*: **A**: The total symmetry of the support moment between injured/dominant and non-injured/non- dominant legs. **B**: Symmetry support knee moment between injured/dominant and non-injured/non-dominant knees. Error bars represent standard deviation. NO, no feedback; SK, kinematic feedback (stick-figure); TG, kinetic feedback (COPnet target).*

4. DISCUSSION AND CONCLUSIONS

The overall goal of this study was to explore whether an in-house-developed real-time targeted feedback application influenced healthy and OA individuals' motor control strategies during double-leg squatting. Healthy subjects altered their squatting strategy when provided with kinematic feedback in the form of a stick figure of the lower limbs, as evidenced by a SYSM that was 4% lower than 100% in this condition. This is in line with our previous data (Al-Amri et al., 2013) that indicated the percentage of total SYSM in healthy subjects changed when they performed a double-leg squat with stick-figure feedback. Patients with knee OA showed a slightly better distribution of the support moment over both legs when provided with kinematic feedback than when provided with no feedback, as evidenced by a SYSM that was 3% less than 100%. To probe this difference between conditions, we investigated extensor knee moments. Healthy subjects reduced the extensor moment in the non-dominant knee and increased the extensor moment in their dominant knee when provided with kinematic feedback, whereas patients with knee OA only altered the extensor moment in their injured knee. This may suggest that healthy subjects focused on the kinematic information presented to alter their body position during the squat as we observed, where patients with knee OA compensated strategies as they might need to improve the presented information of the injured leg.

In both groups of subjects, motor control strategies improved when kinetic feedback was provided. This is evidenced by the comparable distribution over both legs in the two groups. In patients with knee OA, the extensor moment in the injured knee was much smaller in the kinetic feedback condition than in the no feedback and kinematic feedback conditions. This may indicate that the kinetic feedback encouraged them to use their injured knee. In healthy subjects, squat depth (indicated by peak knee flexion angle) was at least 7^{o} lower in the kinetic feedback condition in healthy subjects than in the no feedback and kinematic feedback conditions. By contrast, patients with knee OA maintained a similar squat depth across all three conditions.

Taken together, these preliminary results suggest that both types of feedback may have a greater effect on patients with knee OA than on healthy subjects. The kinetic feedback may be superior to the kinematic feedback for re-educating an individual on how to best perform a double-leg squat. This is not surprising, as the kinematic feedback presented internal information (i.e. the position of body segments or limbs) whereas the kinetic feedback provided an external focus on individuals' movements (Wulf, 2013, Wulf *et al.*, 2010, Wulf *et al.*, 2002, Wulf and McNevin, 2003). Further data are required to explicate these effects of feedback type on squatting strategy.

The main limitation of this study is the small sample size, and additional data are needed before firm conclusions that be drawn. We did not investigate the percentage of moment support of the hip, knee and ankle in both legs. Although it is believed that these three joints should contribute to the total support moment in similar amounts in both legs as far as it is 100%, but studying all three joints would uncover which joint is the main contributor to the total support moment. Further clinical research is needed to explore if the differences observed are clinically meaningful.

In conclusion, the preliminary results of this ongoing research highlight the potential of our real-time targeted feedback to promote subtle alterations in movement strategy during double-leg squatting. If deployed in the clinical setting, the methods outlined herein may improve existing assessment procedures and training techniques for motor control, but further longitudinal research on a larger sample size must be carried out. These preliminary results are very encouraging for our on-going research in which we aim to provide evidence to support this conclusion.

Acknowledgements: The authors would like to thank the volunteers for their time, enthusiasm and feedback.

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Home based virtual rehabilitation for upper extremity functional recovery post-stroke

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ABSTRACT

After stroke, sustained hand rehabilitation training is required for continuous improvement and maintenance of distal function. An ideal home-based telerehabilitation system has to be low cost, easy to set up, effective in motivating the user to use it every day, generate progress reports to the user for self-tracking, and provide daily monitoring to remote clinicians. In this paper, we present a system designed and implemented in our lab: the NJIT Home-based Virtual Rehabilitation System (NJIT HoVRS). A single subject proof of concept study was conducted and demonstrated that this system is easy to access and effective in motivating subjects to train at home.

1. INTRODUCTION

Stroke remains the leading cause of serious, long-term disability in the United States, with over 6.8 million stroke survivors (Go et. al., 2014). Although the incidence of death from stroke has been decreasing due to new medical treatments during the acute episode, this still leaves a significant number of individuals permanently disabled. Only 10% of survivors recover completely, the majority have a long-term or lifelong need for help to perform activities of daily living and require further rehabilitation (CDC, 2007) as a result of a significant brain injury. Deficits in motor control affect the stroke survivors' capacity for independent living and economic self-sufficiency. The impact of even mild to moderate deficits in hand control in particular, affect many activities of daily living.

Intensity and progression have been proposed as key factors in successful stroke rehabilitation. A very recent article, offering a theoretical framework with which to develop future post-stroke clinical trials, proposed that intensity and progression are the active ingredients of a rehabilitation program that drive neural plasticity and lead to positive functional outcomes (Bowden, Woodbury, & Duncan, 2013). Studies have shown that sustained hand rehabilitation training is important for continuous improvement and maintenance of function (Hodics et al., 2006 , Page et al., 2004). If the amount of therapy is critical to rehabilitation, our current institutional limitations undermine the probabilities for successful outcomes. Time constraints and expensive personnel as well as the restricted length of stay in both acute care hospitals and rehabilitation restrain the provision of an adequate dose of training for persons with stroke. After discharge from the inpatient stay, access to rehabilitation therapy can be difficult for some patients. This is due in part to inadequate insurance, lack of transportation, and the patient's dependence on their caregiver. Having access to long-term rehabilitation training anywhere and at any time is necessary for sub-acute and chronic patients to continuously improve their functional abilities. There is a momentum building for increased attention to the development of technological interventions intended to support repetitive on-going home-based practice for better recovery of upper extremity motor function.

Innovative telerehabilitation systems have been developed using information and communication technologies to provide rehabilitation services at a distance. Many studies have developed video-game driven systems from commercially available gaming consoles such as Wii and Microsoft Kinect (Metcalf et al., 2013). Other groups have examined the use of custom-made tele-rehabilitation systems (Adamovich et al., 2005; Turolla et al., 2013). Most of these systems target arm or postural control, and require more space than may be available in the patient's home. These systems do not address hand rehabilitation. There is a vital need to explore intensive home-based upper extremity interventions that focus on the hand. An ideal home-based telerehabilitation system has to be low cost, easy to setup, able to motivate the user to use it every day, generate

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progress reports to the user for self-tracking, and provide daily monitoring to remote clinicians. Exciting new technologies have now made this approach possible and hold promise for long-term benefit. These technological advances - for the first time - allow for virtual reality simulations interfaced with discrete finger and hand tracking that is affordable and easy to use.

The NJIT Home-based Virtual Rehabilitation System (NJIT HoVRS) integrates the Leap Motion Controller and virtual reality technology to provide focused rehabilitation of wrist, hand, and finger movement. This paper presents the design concepts behind the NJIT HoVRS and the results of a proof of concept test. We believe that the NJIT HoVRS is a powerful tool that will give patients access to affordable, effective, and long-term rehabilitation in their home, allowing them to maximize and sustain stroke recovery, while increasing their overall quality of life.

2. SYSTEM DESIGN

NJIT HoVRS has two sub-systems to deliver home-based training: 1) a patient based platform to provide the training and 2) a server based online data logging and reporting system. In the patient's home, a cross platform virtual reality training application runs video games (developed in the Unity 3D game engine using the language C#) on their home computer. The Leap Motion Controller (LMC) infrared tracking device is used to capture motion of the hand and arm movement without requiring wearable sensors that may be difficult to put on independently or could potentially restrain movement.

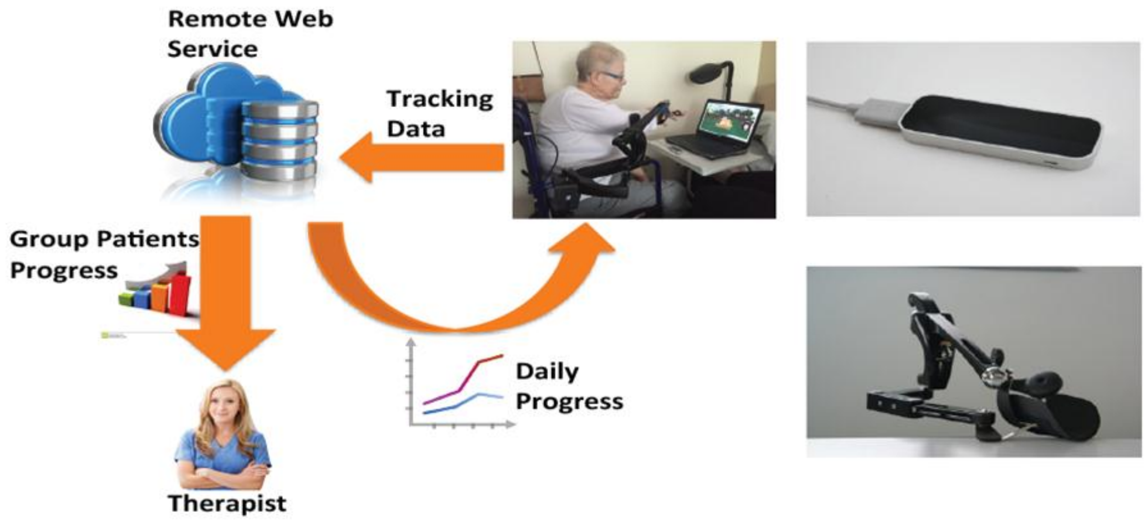

Figure 1. *Left: RAVR-Home architecture design. Upper right: Leap Motion Controller. Lower Right: Armon Edero™ arm support.*

2.1 Hardware

The Leap Motion Controller (LMC) (Figure 1) is a $50 computer hardware sensor that captures detailed hand movement as well as hand gestures. The heart of the device consists of two cameras and three infrared LEDs. A data validation study showed the LMC to be accurate and reliable as long as the target is within its visual area (±250 mm of the LCM center) (J Guna et. al., 2014). The device's USB controller reads the sensor data into its own local memory and performs any necessary resolution adjustments. This data is then streamed via USB to the Leap Motion image API. From there, we programmed the system to feed tracking data into virtual reality activities by calling the Leap Motion API.

If the patient's arm is severely impaired and he/she cannot support the hand against gravity above the Leap Motion Controller, the Armon™ Edero, a spring compensation system, can be provided to the subject (Figure 1). The Edero provides 12 different levels of passive support allowing it to accommodate a wide range of patient sizes and strength levels. It requires a single, setting that can be provided during the patient's initial evaluation. Minimal instruction is required to teach patients to readjust support levels on their own

2.2 Software

A user-friendly GUI interface lists all of the training activities allowing patients to choose which activity they want to begin with using just one mouse click.

Currently twelve games have been developed, each one designed to focus on training a specific hand or arm movement such as wrist rotation or finger individuation. (Figure 2). An avatar is at the corner of all game environments to provide verbal praise and encouragement as therapists usually do in real world. Therapists configuration page can be enabled by pressing “T” for game condition pre-setup, such as work space size, game challenge level, etc. (Figure 3a). All games are downloadable via HoVRS website.

- **Maze**: Player controls the movement of the virtual character through their hand location. The score is defined by the number of spheres the character intercepts along the maze path. The character falls if he deviates from the defined path. As the game level increases in difficulty; the platforms and bridges that the character is guided over become narrower and sharp turns become more frequent.
- **Whack-A-Mole**: The player controls the position of the hammer through arm movement in the horizontal plane. Rotation of the hammer is controlled by pronation/supination. Success score is defined by the amount of moles hit.
- **Soccer Goalie**: The player controls the position of the virtual hand to block the approaching soccer balls from hitting the goal.
- **Bowling**: The player reaches forward and extends their fingers to apply force to the ball to knock over the pins.
- **Fruit Picking**: The player must reach and use a pinch movement with their thumb and forefinger to pick apples and oranges from trees and sort them into the correct basket to increase the score.
- **Fruit Catching:** To catch the fruit, the player controls location of a collection basket through horizontal arm movement. To increase the score, the player uses forearm pronation/supination to drop the collected fruit into a second basket. The frequency of falling fruit decreases when the player misses 25% of the falling fruit
- **Car Game:** The player practices opening and closing their hand to control the car speed. Closing the hand slows the car down allowing it to maneuver over speed bumps.
- **Hand Flying:** The plane speed is constant. The player controls vertical position of the plane by opening and closing their hand. Success score is defined by the number of floating spheres intercepted.
- **Wrist Flying:** The plane speed is constant. The player controls vertical position of the plane by changing the pitch of their hand at the wrist. Success score is defined by the number of floating spheres intercepted.

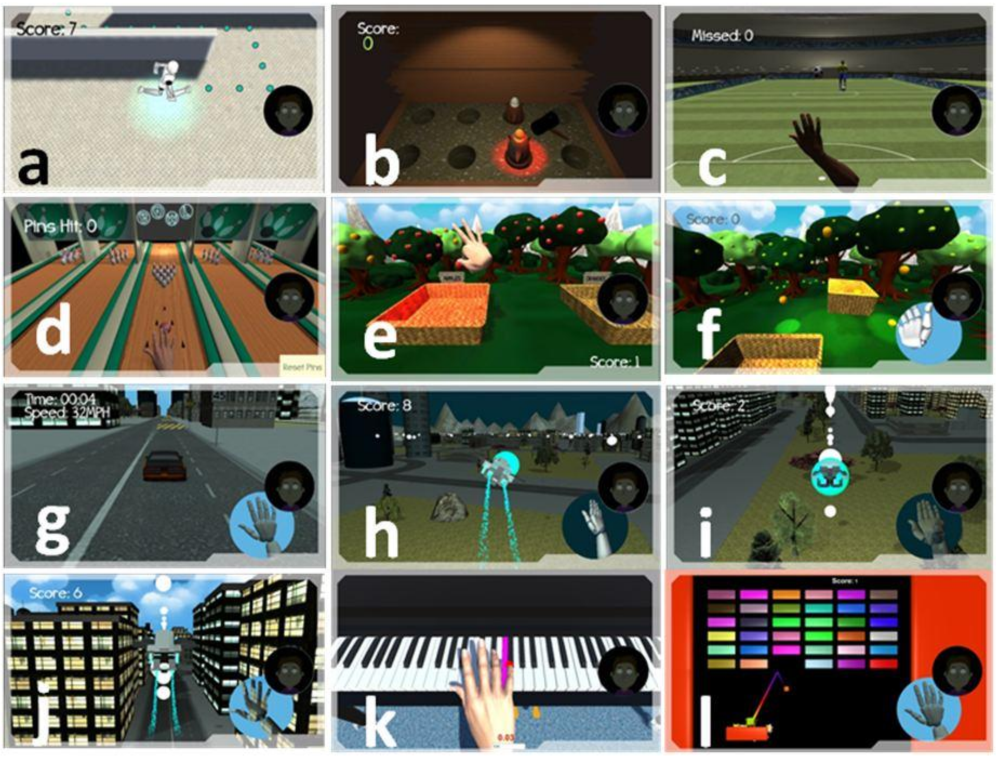

Figure 1. *Left: RAVR-Home architecture design. Upper right: Leap Motion Controller. Lower Right: Armon Edero™ arm support. Figure2. a: Maze, b. Whack-A-Mole, c. Soccer Goalie, d. Bowling, e. Fruit Picking, f. Fruit Catching, g. Car game, h. Hand Fly, i. Wrist Fly, j. Arm Fly, k. Piano, l. Breakout.*

- **Arm Flying:** The plane speed is constant. The player controls the horizontal position and roll of the plane by moving their arm left and right and pronating/supinating their forearm. Success score is defined by the number of floating spheres intercepted.
- **Piano:** The player plays a song by pressing the highlighted key with the indicated virtual finger. The amount of finger individuation required to successfully press any keys increases as the player progresses. However, it scales back down when they are unable to hit the key for 6 seconds.
- **Breakout:** The paddle used to direct the ball follows the palm position of the player. The ball is directed by bouncing off the paddle and hitting the bricks above to clear the screen.

2.3 System Calibration and Hand Position correction

A comprehensive calibration procedure (Figure 3b) is used to measure each subject's active range of motion within the LMC visual area and this range is scaled to fit into the video game virtual environment. To create greater ease of use, games have been designed to display a red frame (Figure 3c) to guide the subject back to the LMC visual area whenever his/her hand deviates from the calibrated range.

Figure 3. *a. Therapist setup interface; b. Calibration interface; c. Hand not visible warning.*

2.4 Data Collection

Performance and kinematic data collected during rehabilitation training using the NJIT HoVRS is securely transferred to Amazon Simple Storage Service (S3) at the end of the each training session for offline analysis. Patient data is automatically processed to produce daily progress reports. Therapists can securely access the reports through a password protected website, which will also host system updates.

3. SYSTEM VALIDATION

In order to evaluate NJIT HoVRS' ease of use and reliability, a 45 year old female patient with moderate hemiparesis of the upper extremity (UEFMA = 45) due to a cortical stroke was recruited. She was a police detective prior to the stroke and was able to return to full time deskwork 6 months after the event. She lives alone but her family lives nearby and gave her a lot of support during her rehabilitation. She had little to no video game experience prior to this training. The system was placed in her home. Without help from the therapist or engineer, she successfully finished 7 thirty minutes training sessions utilizing all twelve of the games at least twice (Figure 4).

3.1 Car Simulation

As shown in Figure 5 (left panel), the subject was able to maintain her hand above the Leap Motion and control virtual car speed by opening and closing her hand. As the simulation went on, she gradually opened her hand more than she was capable of during the initial calibration.

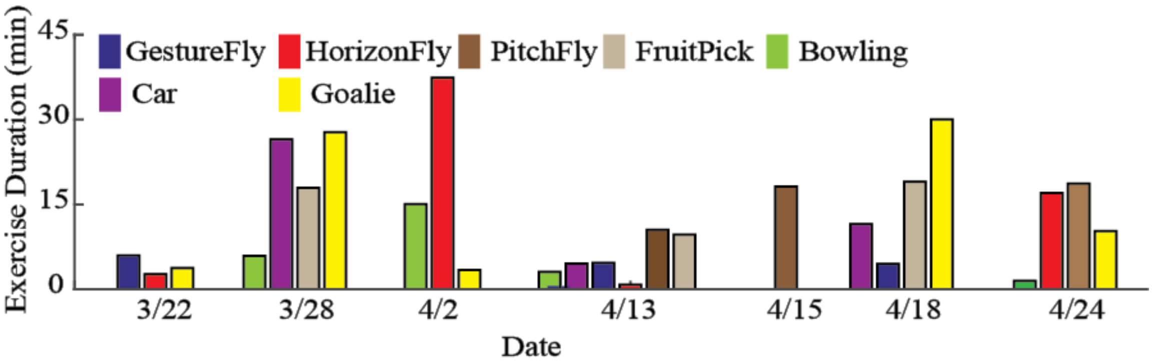

Figure 4. *Exercise duration for each gaming activity over one month of therapy, as reported by the HoVRS website.*

Proc. 11th Intl Conf. Disability, Virtual Reality & Associated Technologies
Los Angeles, California, USA, 20–22 Sept. 2016
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3.2 Maze Simulation

In the Maze simulation (Figure 5, right panel), after successfully reaching the target, the subject will advance to a higher level that requires more hand stability. If the subject fails to reach the target, the score collected from the current level will be deducted and the subject starts again from the beginning of the current level. As shown in Figure 5 right, our subject was able to successfully pass the first four easy levels. However, as difficulty level increased, the subject started to slow down and make multiple attempts to complete fifth level.

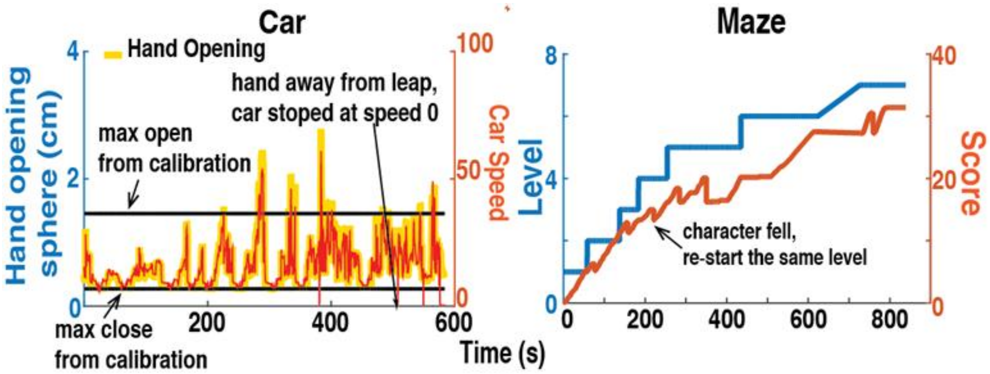

Figure 5. *Performance during a single session of Car (Left) and Maze (Right) simulations. Left panel: Two horizontal lines indicate maximum hand closing and opening during initial calibration. Arrow indicates moment when hand tracking was lost and the car speed dropped to zero. Right panel: Arrow indicates moment when the avatar fell off the maze plane and the game restarted at the beginning of the level.*

3.3 Questionnaire

In a post-training questionnaire, the subject noted the system's ease of use and a desire to incorporate the system as part of her on-going therapy. Subject felt that this therapy system was engaging. In her comments, she said that the system is easy to use, and she almost forgot that she was participating in rehabilitation training while she was focusing on trying to complete the computer tasks. Her arm was tired after doing the training, but not her hand. She felt this system would improve her hand motion. She wished it could have been part of her original therapy and wanted it to be part of her on-going therapy. Subject said most of the games were engaging. She was able to understand the requirements and learn how to play them quickly. The easiest game for her was the Car simulation because it had a one-dimensional control requiring only hand opening and closing to manipulate the car's speed. Her favorite game was the Arm Flying simulation because its soothing music made her relax and enjoy the training. The most difficult game for her was the piano because it required both arm stability and finger individuation. The most confusing game was Whack-A-Mole because different lighting and random appearance of the moles provided too much information and caused confusion about how to proceed. The most non-intuitive game was Soccer Goalie because the orientation of the virtual hand and the real hand did not match. The virtual hand displayed in the virtual environment was vertical with the palm facing forward, while the real hand was horizontal with the palm facing down.

3.4 System Server for Data Monitoring and Visualization

All training data could be accessed remotely from the data server via HoVRS website. The therapist can access daily training data of a specific subject for a specific game activity via website. As shown in Figure 6, therapist chose to display daily maximum hand opening value from game GestureFly on website. The therapist sent a short text messages to the patient whenever there was new training data shown on the server side as a way to praise her effort and encourage continued participation. The data showed that repeated performance of several simulations resulted in increased finger opening as measured by the system.

4. DISCUSSION

We intend to bring a "wellness" approach to the achievement of independent upper extremity manipulation and function for people post-stroke. The National Wellness Institute (mailto:http://www.nationalwellness.org) encourages "a conscious, self-directed and evolving process of achieving full potential." Through the development of an easy to use and engaging home-based virtual reality exercise program we modeled the wellness concept of continual self-directed exercise to allow people with hand and upper extremity motor deficits to achieve their full potential. NJIT HoVRS is a low cost, easy to setup, reliable and engaging home-based hand rehabilitation system. Virtual reality simulations are engaging and the subject was motivated to play them for a long period of time. Currently, there is little available for home-based hand therapy (Hayward, Neibling, & Barker, 2015). The advantage of this home-based system is its focus on hand-based simulations. Our objective was to provide markerless hand tracking (LEAP) and simple support of arm motion in 3-dimensional space to allow the patient to move freely, while it helps them keep their hands over the LEAP's effective range. Clear online directions, delivered visually and aurally through imaginative avatars allow the individuals to practice independently. Novel algorithms provide safe and effective interactions with the serious games. Despite this complexity, the use of novel technologies makes this affordable system easy to use. Compliance with home-based exercise programs is low. We believe strongly that the NJIT-HoVRS home-based system will effectively deal with compliance issues through the engaging games, the easy to use system (no donning and doffing difficulties), the enticing encouraging avatars, the success algorithms and the instant availability of daily achievement graphs. This self-paced, independent home practice is consistent with a "wellness" approach that should empower stroke survivors to take an active self-directed approach to their rehabilitation.

Init	Day	Date	Game	Duration	MaxOpenWholeHand	MaxCloseWholeHand	ROM WholeHand	ROM ThumbPIP	ROM ThumbMPJ
LK	1	3222016	GestureFlying	398	413.1399616	186.0786919	227.0612697	24.80610692	0.308311581
LK	2	4132016	GestureFlying	313	415.1083938	183.1318084	231.9765854	17.10316018	0.000151885
LK	3	4182016	GestureFlying	300	430.6113351	190.6208496	239.9904854	30.12570069	1.192360472

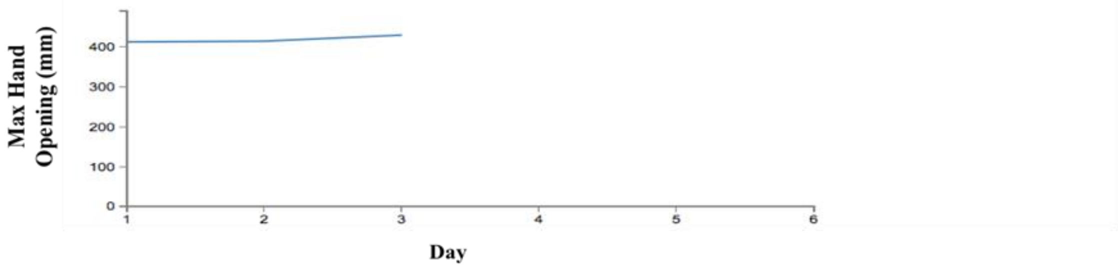

Figure 6. *Therapist can monitor subject's daily progress via HoVRS website. Plot shows the sum of distances between the palm and five fingertips.*

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Kinect controlled game to improve space and depth perception

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ABSTRACT

Space perception is one of the most important skills of human life. Space perception is not a congenital faculty of human beings, but it evolves during the first few years of life. Experts are of the opinion that depth perception can be improved during the first 15-16 years of life. It is essential to perform depth perception in several occupations. We have developed virtual reality game with animations that were used by students to practice space perception tasks and to acquire better space perception. The game is controlled via Kinect sensor.

1. INTRODUCTION

The stereoscopic vision, depth perception is very important ability to navigate in the world. Unfortunately not everybody has these skills, or has only limited stereoscopic vision or depth perception. The number of these people is about 3-5 percent of the population. Professionals use several methods developing these people's spatial perception. This method includes solving visually difficult tasks. These tasks have several variants, nowadays in the form of videogames. The goal of our project was developing a game. Using this game the user can practice with playful tasks and can go through visual tasks. The ordinary repetitive visual tasks sometimes become a bit boring or tiring; therefore our goal was to keep the interest of the user. It was one of the most important points in the developing process to motivate the user (Bavelier et al., 2015), (Indu et al., 2015), (Levi & Li, 2009). The other motivating part is using a new input device, the Kinect sensor. The user can control the game by his/her movements using Kinect sensor without any another input devices. Kinect sensor enables users to control and interact with the computer without need for another game controller, through natural user interface using gestures. The device detects the whole body of the user. It can follow the users' joints. Therefore Kinect as input device is more natural for manipulating 3D object in VR, like manipulating via keys or mouse. Researchers in Nottingham used VR technology for binocular treatment of amblyopia (Waddingham, 2006). Sanchez and his colleagues made a research teaching the blind children to find their way by playing video games. Their result is that the immersive and highly interactive nature of the software greatly engages the blind users to actively explore the virtual environment. This, in turn, generates an accurate sense of a large-scale three-dimensional space and facilitates the learning and transfer of navigation skills to the physical world (Sánchez et al., 2012), (Merabet et al., 2012).

The recent research is a continuation of our previous research, where similar tasks were programmed by VRML. Our future plan is making efficiency tests comparing the efficiency of games, the oldest and the newest one. The new game is implemented in C # .NET.

2. THE GAME

The purpose of the software is to make the user able to improve his/her stereopsis via solving visually difficult tasks, presented as games. The software contains 4 games: Rift-, Rotate-, Net- and NetFromCube games.

2.1 The Rift game

The game imitates the classic children's game in which a specific shape is pushed through a rift. The program uses cubes to contract shapes. Both the rift and the shapes are built from these cubes. Figure 1 is a screenshot of the "Rift" game. The task is to choose the adequate object from the 4 alternative shapes, which can go through the rift. The user can rotate the shapes, if he/ she doesn't know the right solution at a glance.

2.2 The Rotate game

The game shows a cube on the top half part of the screen. There are 4 other cubes on the down half part of the screen. Of course the user can see only 3 surfaces of a cube, like in the real world. The task is choosing the cube(s) from the 4 cubes, which is/are the same as the cube on the top of the screen. But it can be seen in a rotated position (Figure 2).

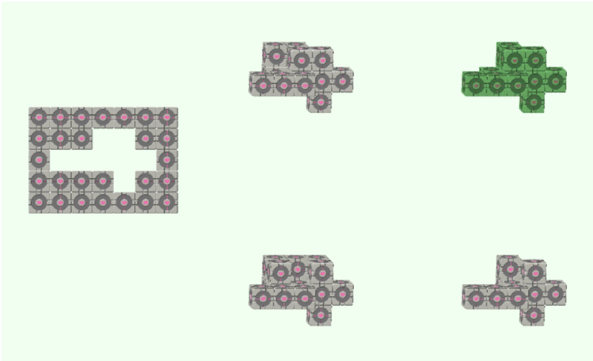

Figure 1. *The Rift game….*

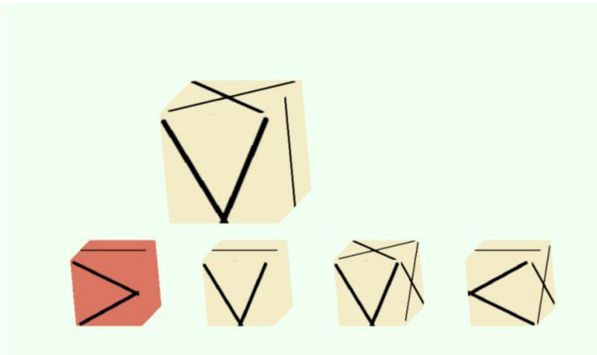

Figure 2. *The Rotate game.*

The appropriate solutions are the first cube on the left side and fourth cube on the right side (Figure 2). The cube on the left side was rotated with 90 degrees along the positive direction of the z axis. The cube on the right side was rotated with 90 degrees along the negative direction of the z axis.

The user can rotate the cube horizontally by swinging his/her hand to the appropriate direction (Figure 3). These movements rotate the cubes by the y axis. The user can rotate the cube up or down by swinging his/her hands right or left. The user has to keep his/her hand half a second long at the up swinging, and after they can put the cube in the original position. This waiting time distinguishes the two gestures (up or down).

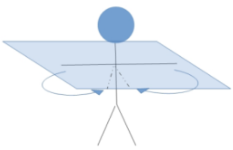

Figure 3. *Swinging movement.*

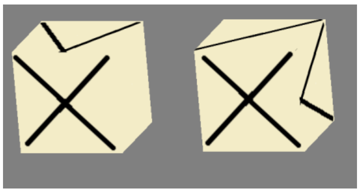

Figure 4. *Rotation along the negative direction of the z axis.*

2.3 The Net game

In this task the user has to select net(s) from which he/she can fold a cube. Figure 5 shows a level of the "Net" game. The program includes all the possible nets for the cube and some bad nets too. The program puts the nets randomly onto the screen; of course it contains minimum one right solution. The user can fold the right solution and make a cube.

If the user can't solve the task mentally, he/ she can fold the net. Two sides of a net are highlighted with red colour in the first alternative net in Figure 5. An edge is between these two rectangles. These two rectangles are folding along by the edge between them. The user can select another edge by gestures. These gestures are: up, down, right and left movement of the user's hand.

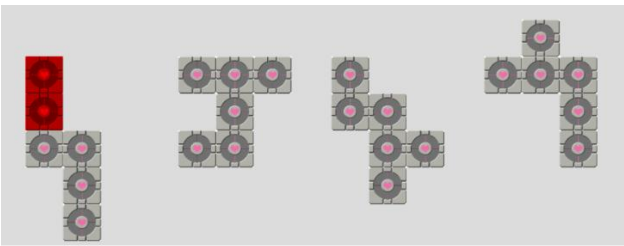

Figure 5. *The Net game.*

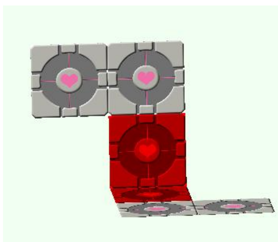

Figure 6. *A folded net.*

2.4 The NetFromCube game

This game is a combination of the previous two games. The user can watch a cube on the upper part of the screen and 4 alternative nets down. But there are some patterns on the surface of the nets. The user has to select a net or several nets from the alternative nets, fold it/them into a cube to get the basic cube shown above the alternatives (Figure 7).

The right solutions are the right side two nets on Figure 7. It is easy to see, because a line is joining to the upper point of the V shape on both nests. If the user can't see the pattern, he/she can fold the net and after it check the cube by rotating it. These lines on the bad nets are in wrong directions.

The above cube is generated by the program randomly. The program uses some rules. The good and bad nets are made by using these rules. When the program creates the original cube, it places a single non-rotationally symmetric figure at a surface. This figure can be turned to another figure. Such a figure is X and I. The places of these figures are obviously correlating with the non-symmetric figures.

A basis for generating good networks is that the non-symmetric figure, which can be seen from the front viewpoint, is put into different places on the net, and the other sides should be placed accordingly. As it is put in the centre of the upper row or it is on the top of the T shape (Figure 7).

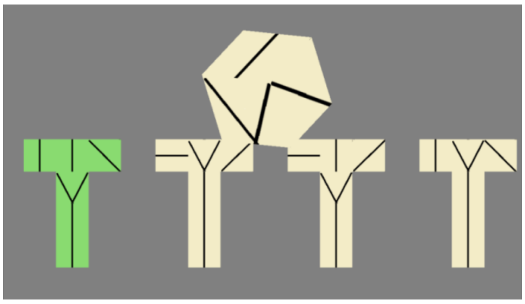

Figure 7. *The NetformCube game.*

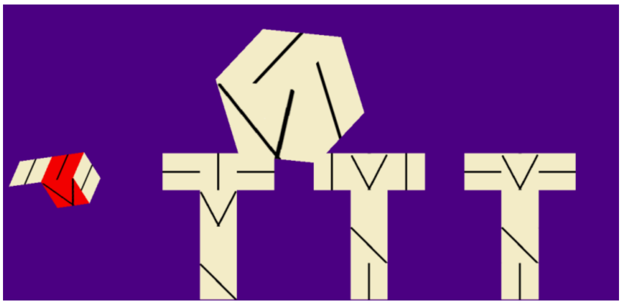

Figure 8. *Examination of a net.*

The user can examine the alternative nets during the game play (Figure 8). Figure 8 shows that the first net is not the good solution, because after folding the patterns on the surface aren't the same as those of the original cube on the upper part of the screen, as the straight line on the right side of the V shape of the first net is in wrong direction.

2.5 Controlling the games with Kinect

The possible gestures are the following:

1. Next alternative: right arm parallel to the shoulders, then moving upwards so it will be parallel to the body. The gesture should be done in half of a second by default, this value can be changed in the settings.
2. Guess/ next alternative: same as above, but with left hand.
3. In case of rift game, one can inspect the alternative by reaching out with right hand and then moving it.
4. In case of Cube game one can inspect the cube after guessing:
    - i). Tilt on Y: arm parallel to shoulders, then moving it toward the screen, so it will be perpendicular to the body.
    - ii). Tilt on X:
        - I. Down: arm rested next to the body, then moving it upward to the ceiling then lowering it. Hand must rest for shorter time in the raised position then the given setting, by default half of a second.
        - II. Up: same as above, but hand must rest more as the given value
5. In case of Netgame: moving among edges: as in the cube rotation game, according to the directions.
6. Fold edge: raise right foot by 30 cm.

2.6 Adding new side and new language

Program can use textures added by the user. To add new texture, one has to copy that in the textures folder, then adopt the file name in the settings.ini file, with the appropriate symmetry property (halfTurn, quarterTurn, noSymmetry). The program can accept files with bmp extension.

Program can accept new language defined by the user. First, create the text file according to the existing ones with .lan extension, and then adopt the file name in the setting.ini file: add the filename separated by comma to the variable “availablelan”.

3. TESTING THE GAME

The testing process was very important both during the development of the parts, functions of the game and after the completion too. It is important that the future users can test the game, not only the developers. The purpose of the testing is not only to find the bags, but to get user evaluation in order to refine the game. Three university students were asked to test the game and fill in a questionnaire based on several criteria.

The results of the questionnaire show that the hardest game is the Net game. It is understandable, because one of the hardest cognitive tasks is to think up if the net is a net of a cube or not. Maybe this complexity makes it less enjoyable than the other games, but the interaction is more interesting (to fold a net), than only turn a cube like in the other games. It could be also motivating. This interaction rounds out the usual interaction possibilities. It makes more spectacular changes with an object compared to the others; therefore it could arouse the users' interest. One question was asked about the accuracy of the gestures. It was valued in a 5 point Likert scale. The average result was 4. It could be a good rate. Only a bit more precisely, a bit finer accuracy is needed for making the game more the enjoyable.

To sum up, the observers evaluated the game with a high score. It means, the software looks like a game and not a teaching application to develop someone's skills, which was one of our main goals.

4. CONCLUSIONS

An easy to use, enjoyable game was completed for the development of space perception. The game is controllable by modern input device, Kinect sensor. It engages the users' attention and motivates them; moreover it makes the game more enjoyable. In this way the user can enjoy the 3D graphics in a playful way and they do not have the feeling that this application is a teaching software.

Our colleagues gave us useful advices to increase the ergonomics of the game. The quality of gestures has improved based on their advices and the result of the questionnaire. We hope that this game can be useful among the other softwares developed for space perception.

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Influence of point of view and technology in presence and embodiment

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ABSTRACT

Presence and embodiment have been reported to modulate the experience in virtual worlds. However, while these perceptions are presumably interconnected, little research has been done to unveil the nature of this relationship. In this study we show how presence and embodiment are modulated by the point of view of a virtual body and the enabling technology while being engaged in a virtual task.

1. INTRODUCTION

The sense of presence has been suggested to be the key mechanism that makes virtual reality work. Even though there is no standard definition, presence can be understood as the psychological state in which the virtuality of the experience is unnoticed (Slater, 1999). Presence has been shown to be modulated by both human (demographic, psychocultural, and clinical) and media characteristics (technology used and content of the virtual world). Technology facilitates immersion, it is, the delivery of an illusion of reality to the senses of a human participant, as well as presence (Slater, 1999). As a proof, immersive head mounted displays (HMD) can provide higher level of presence than PC monitors, even though differences can be non-significant (Mania et al., 2001; Baños et al., 2004). However, the relationship between immersion and presence is not one-to-one. Emotional valence has been shown to increase presence even with low levels of immersion (Baños et al., 2004). Embodiment is a multi-component psychological construct that involves body-ownership, the sense that the body that one inhabits is his/her own, localization, the sense that the body is located congruently with the sensory inputs, and agency, the sense that one can move and control his/her body (Tsakiris, 2010).

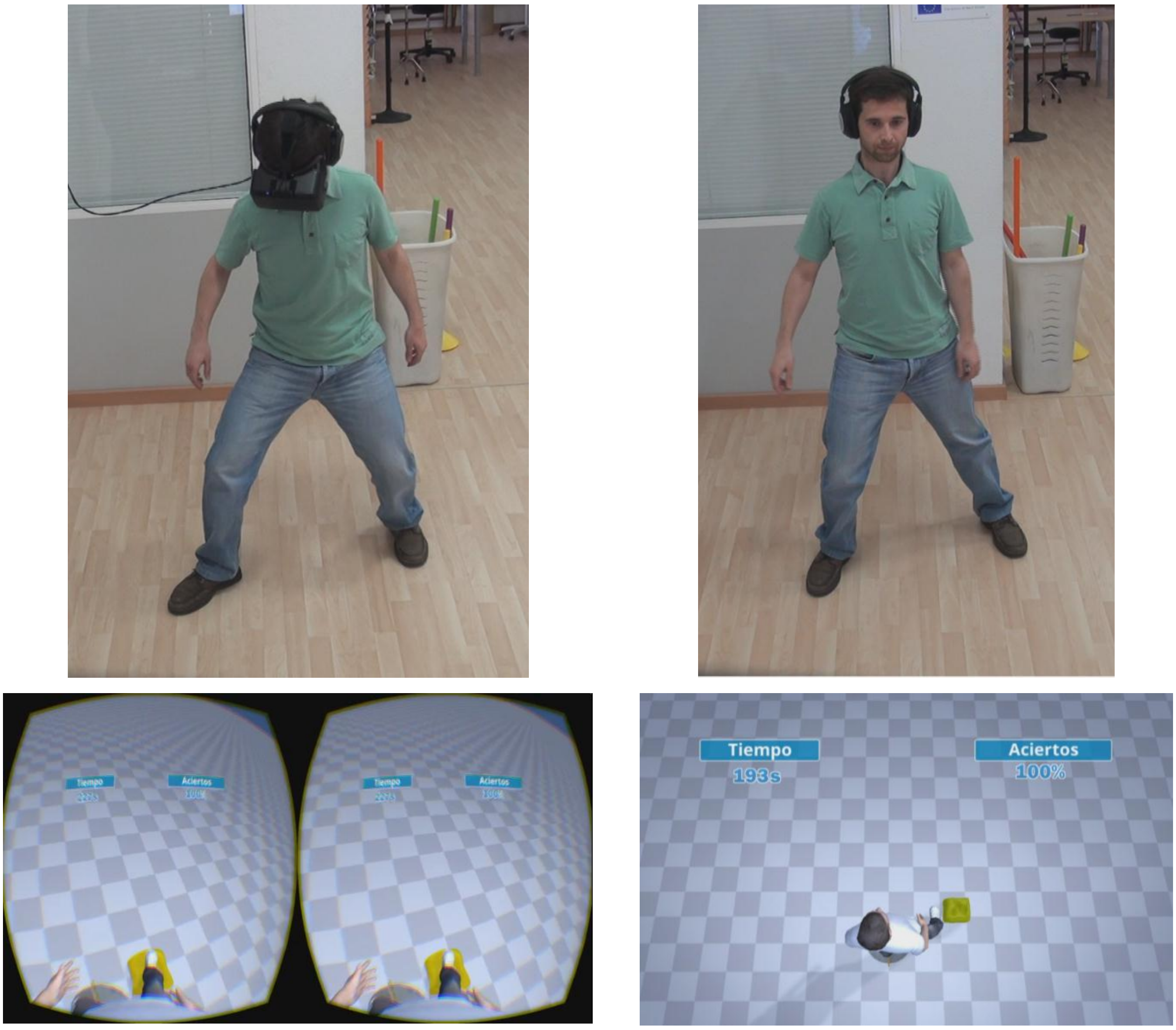
When interaction in the virtual world is mediated by virtual bodies or avatars, special considerations about presence and embodiment should be made. With regards to the presence, the relationship between self-construal, the extent to which individuals view themselves either as an individual entity or in relation to others, and this sense has been previously revealed (Jin et al., 2009). With regards to embodiment, different studies have also shown how virtual limbs and bodies can come to feel like real limbs and bodies (Slater et al., 2009). Similarly to presence, not only the technical aspects but the characteristics of the avatar modulate embodiment. Hence, the use of a first-person perspective has been shown to elicit higher ownership over avatars (Slater et al., 2010; Pavone et al., 2016), and, furthermore, the characteristics of the embodied avatar have shown to modulate the users' perception of the virtual world and their behaviour (Yee et al., 2007).

Even though presence and embodiment seem to be mutually dependent little is known about the nature of this dependence. The objective of this study was to examine the sense of presence and embodiment elicited while interacting with a virtual environment (VE) using different immersive settings and point of views.

2. METHODS

2.1 Instrumentation

Visual feedback was provided by an HMD in the first-person condition (Figure 1.a) or a TV in the third-person condition (Figure 1.b). The Oculus DK2 (Oculus VR, Irvine, CA) was used as HMD. The device has a resolution of 960x1080 per eye, a field of view of 100º, an update rate of 60 Hz and provides its Euler angles (yaw, pitch, and roll) through a built-in gyroscope and accelerometer. A 60″ LED Screen (LG, Seoul, South Korea) with a resolution of 1920x1080 was used for the other condition. Auditory feedback was provided by a Bluetooth headset HDR 170 (Sennheiser electronic GmbH & Co. KG, Wedemark, Germany). Motion tracking was provided by a Kinect™ for Windows® v2 (Microsoft, Redmond, WA), which provided the position and rotation of the main joints of the participants at 30 Hz. In the first-person condition the orientation and acceleration of the head was retrieved from the Euler angles of the HMD. A high-end computer was used to generate VEs in both conditions. The hardware components of the computer included an 8-core Intel® Core™ i7-4790 @ 3.60 GHz, 8 GB of RAM, and a NVIDIA® Geforce® GTX 745 with 4GB of GDDR3.



(a) *(b)*

Figure 1. *Participants interacting with the exercises and snapshots of the virtual environment in the (a) first and (b) third-person condition.*

The VE consisted of a checkered floor with a darkened circle of 25-cm radius in the middle of the scenario. Different geometric items (cubes, spheres, and cones) of 20 cm^3 volume appeared around the circle in eight different areas defined around the circle. Participants were represented with a male or female avatar that mimicked their real movements in the VE. The point of view in the VE depended on the experimental condition: the VE was seen through the eyes of the avatar in the first-person condition (Figure 1.a) or from an overhead perspective in the third-person condition (Figure 1.b).

Proc. 11th Intl Conf. Disability, Virtual Reality & Associated Technologies
Los Angeles, California, USA, 20–22 Sept. 2016
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The objective of the exercise was to step on the shapes with the nearest foot while maintaining the other foot within the boundaries of the circle. After each step, the foot had to be repositioned towards the body and enter the circle. Items disappeared after 30 s if they were not reached. In contrast to previous studies with this VE (Llorens et al., 2015; Llorens et al., 2015), the two rear areas were disabled in both conditions because they could not be seen in the first-person condition. 3D auditory cues were provided when items appeared and disappeared. In addition, a cheerful and upbeat background music was used to motivate the participants. During the exercise, the remaining time and the success percentage were displayed in the VE. After the exercise, the total success percentage was shown.

The virtual environment was designed using Unity 3D (Unity Technologies, San Francisco, CA).

2.2 Participants

Twenty-five participants (18 men and 7 women) without musculoskeletal or cognitive disorders were recruited for this study. Two of them experienced cyber sickness during the exercise (in the first-person condition) and were not able to complete the experiment. Consequently, their data were not included for analysis. A total of 23 subjects with a mean age of 28.7±6.4 years old, 23.3±5.8 years of education, and a self-rated experience with videogames of 7.1±2.89 over 10 were included in the study (results expressed in terms of mean and standard deviation). All of the participants provided written informed consent before taking part in this study.

2.3 Procedure

All the participants interacted with the exercise for 10 minutes in the first and third-person condition in counterbalanced order. Two experimenters were in charge of conducting the sessions, equipping the participants, and providing safety, guidance, and comfort. Before each condition, participants were briefly introduced to the technology and the objectives of the exercise.

After each condition, the presence and embodiment experienced during the exercise were assessed using two questionnaires. The presence questionnaire consisted on three items rated on a 7-point Likert scale that evaluated the sense of being in the VE, the extent to which the VE becomes real, and the extent to which the VE is thought of as a place visited (Slater et al., 2000). The embodiment questionnaire evaluated in 10 items rated on a 7-item Likert scale the extent to which the avatar movements answered to the participant movements, the body of the avatar belonged to the participant, and the avatar was in the same location than the participant (Longo et al., 2008). Scores to both questionnaires were averaged and ranged from 1 to 7.

2.4 Data analysis

Scores to the questionnaires after both conditions were compared with independent sample t-tests. The α level was set at 0.05 for all analyses (two-sided). All analyses were computed with SPSS for Windows®, version 22 (IBM®, Armonk, NY, USA). Investigators performing the data analysis were blinded.

3. RESULTS

Significant differences in presence and embodiment were found in both conditions (Table 1). When analysing the different constructs of embodiment, user's perspective and technology proved to influence body-ownership and localization, but no agency.

Table 1. *Scores to the presence and embodiment questionnaires. Results are expressed in terms of mean and standard deviation.*

Construct	Third person	First person	Significance
Presence	4.03±1.25	5.32±0.82	p=0.000
Embodiment	5.05±1.11	5.57±0.81	p=0.008
Body-ownership	4.36±1.40	5.30±1.00	p=0.001
Localization	4.74±1.48	5.36±1.00	p=0.036
Agency	6.04±0.82	6.04±0.69	NS

4. CONCLUSIONS

Users felt significantly higher sense of presence when the VE was displayed in first person and used the HMD. Our results could support previous studies (Mania et al., 2001; Baños et al., 2004) and maybe evidence how the improved features of the current HMDs could intensify these effects, which would support the influence of immersion in presence. This finding could be specially relevant as far as the latest technological advances could modify some old paradigms of VR, which should be revisited with the current technology.

Users also reported higher embodiment of the avatar when it was shown in first person through the HMD. When analysing the constructs separately, differences were only found in body-ownership and localization but not in agency. It is, while participants felt that they were able to move the virtual body regardless of the point of view and the technology, they only felt that the virtual body was their own and that it was located as their real body when they saw the VE in first person though the HMD. Even though the design of the study did not allow to isolate the effects of the point of view and the technology, our results could support the important role of vision on embodiment and, beyond this, the role of the previous experience on its constructs. The congruence in the visual stimulation between the real and the virtual world (life is experienced in first person view), could have motivated higher results on ownership and localization. Interestingly, the congruence in the continuity of a virtual body provided higher sense of ownership while having no effects on agency (Perez-Marcos et al, 2012). These findings should be confirmed in further studies because they may be of great importance when designing virtual experiences.

Acknowledgements: This study was funded in part by Ministerio de Economía y Competitividad (Project NeuroVR, TIN2013-44741-R and Project REACT, TIN2014-61975-EXP), Ministerio de Educación y Ciencia Spain, Projects Consolider-C (SEJ2006-14301/PSIC), "CIBER of Physiopathology of Obesity and Nutrition, an initiative of ISCIII" and the Excellence Research Program PROMETEO (Generalitat Valenciana. Conselleria de Educación, 2008-157).

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Application of a rehabilitation game model to assistive technology design

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ABSTRACT

Games are increasingly used by physiotherapists in rehabilitation and the gamification of rehabilitation processes is an increasingly common practice. A key motivation for injecting playful or gameful activities into rehabilitation is to enhance engagement for home rehabilitation exercises by making them more fun. Multi-disciplinary cooperation is important in designing gameful activities. However, system design and development can be challenging between software engineers, health professionals, and academics due to terminology and knowledge differences. Sometimes skill and knowledge levels are also not optimal within the team. In both cases a comprehensive Rehabilitation Game Model (RGM) built on established principles, with an associated tool, can facilitate an effective design process. Factors that can be missed without use of a structured process include the potential impact of symptoms and variation in user demographic, personality or interaction preference. Our RGM helps game designers put a greater focus on variations between people in designing rehabilitation games. In this paper we provide an overview of the RGM and extend it to include rehabilitation aspects. We apply it to upper arm stroke rehabilitation. We present a representation of the output from the RGM that can form the basis for advice and guidance to serious game designers of upper arm stroke rehabilitation games.

1. INTRODUCTION

The creation of serious games for use in assistive technologies is becoming increasingly popular. Physiotherapy is particularly applicable to games and gamification since physical rehabilitation programmes can potentially be mundane, are often challenging, and require adherence to prescribed schedules. Gamification is the application of game-design elements and game principles in non-game contexts (Deterding et al, 2011) so as to improve processes and systems in relation to a broad range of contexts such as user engagement, organizational productivity, learning, motivating behaviour changes, as well as attitudes to diet and physical exercise. Recently, gamification has been used in rehabilitation to help people become more engaged in their rehabilitation (Szaniawski et al, 2015), and to encourage them to complete their exercises more regularly and consistently. Gamification can embed principles of psychology in the form of reinforcement of positive behaviours and rewards mechanisms to improve adherence through motivational techniques. Games and virtual reality (VR) can be used to add fun to the process through structuring the exercises in entertaining contexts and embedded gamification features. To have an effective rehabilitation game, the game design needs to be adapted to the type of exercise and also to the people who will play it. Designing and creating effective assistive technologies can be difficult and time consuming due to the complexity of rehabilitation requirements. Development of games and VR rehabilitation systems is especially challenging as it adds another dimension to the expertise required of the multidisciplinary team; requiring knowledge of game design, game asset creation, technical game development skills, software engineering, physiotherapy and end user experience. This is a challenging process, even for experienced designers, and so we have developed the Rehabilitation Game Model (RGM) (Holmes et al., 2015) to guide the process.

1.1 *The Rehabilitation Game Model (RGM)*

Having a structured tool that aids the creation and evaluation of personalised games is important for communication between non-professionals and professionals across multiple disciplines during the design and development process. Facilitating the collaboration between disciplines as early as possible helps focus efforts on games that accounts for personality- rehabilitation guidelines and exercises- as user gaming preferences to encourage enjoyment. Thus allowing all parties to clearly understand and quickly define a personalised game idea ready for development.

The RGM guides the design and implementation of effective rehabilitation games and consists of mappings three core aspects (Fig 1): a gamification typology, a comprehensive set of game design patterns, and core behaviour change techniques from psychology. The RGM is applied to a rehabilitation context such as upper arm stroke rehabilitation. A gamification typology (such as Marczewski, 2015b) takes into account variation between types of people and the ways that they may be motivated. In the RGM, gamification types are based on Marczewski's (2015a) Hexad. The Hexad gamification types are in part based on well-known player types (e.g. Bartle, 2013), and in part on other psychological personality models including Self-Determination Theory. In our application of the RGM these are mapped to a set of game design patterns by Bjork & Holopainen (2004) containing 300 game mechanics that can be used in a number of combinations to design novel gameplay suited to Marczewski's Hexad gamification types. Behaviour change techniques (Michie et al, 2014) are also integrated and mapped against the game mechanics in order to shape behaviour and help tailor games to encourage improved adherence to exercise. The six Hexad gamification user types are:

1. *Disruptor*–motivated by change they want to disrupt the system directly or through others with a positive or negative outcome.
2. *Free Spirit*–motivated by autonomy they want to explore, be creative and have choices.
3. *Achiever*–motivated by mastery they are all about self-improvement and like to be challenged in order to better themselves.
4. *Player*–motivated by rewards they are selfish and do what is necessary to win or be better than others.
5. *Socializer*–motivated by relatedness they want to create a social connection with others.
6. *Philanthropist*–motivated by purpose they need a purpose for interacting and are also altruistic towards others.

Figure 1 provides an operational illustration of the RGM, integrating the well-known MDA (mechanics, dynamics, aesthetics) model of a game. The core component is the **game** and respective game mechanics are constructed from fundamental game design patterns. A model of **player** motivation is embedded using gamification types (in this instance Hexad types). Player behaviour is modelled using **COM-B** (Michie et al, 2014) (Capability, Opportunity, Motivation for Behaviour change) and in particular key behaviour change techniques which are mapped to a particular group of game mechanics and thus player type (see colour coding). Player interactions on the game mechanics (Dynamics) result in a change of game state and the provision of feedback to the player. Feedback to the player can be visual, auditory, or haptic and is central to the user experience (Aesthetics). Game mechanics can promote certain behaviour changes according to the challenges brought about by the particular player type's interactions on the games mechanics. For example, Achievers may want to fight (interact) against a boss monster (game mechanic) to test their learnt skills and knowledge, giving a sense of progression when achieving this high level goal (feedback, behaviour technique (Goal setting) & aesthetics).

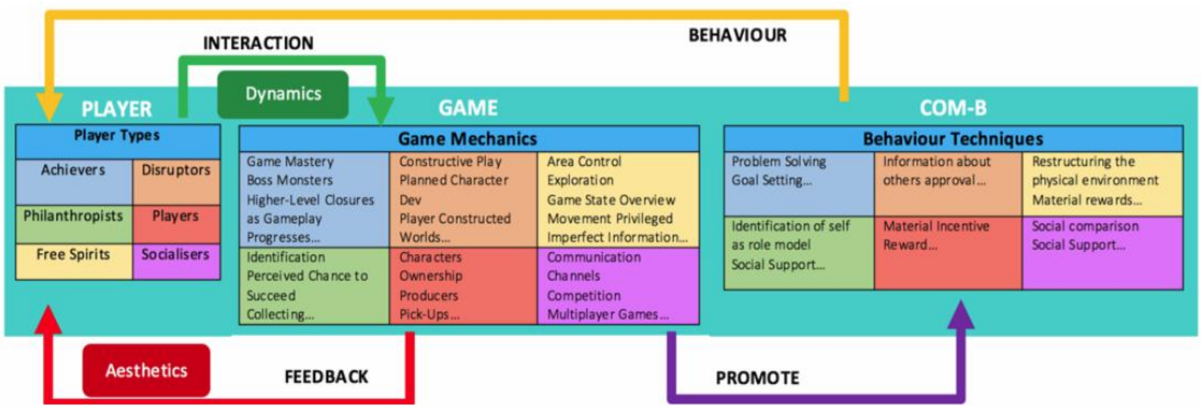

Figure 1. *The Rehabilitation Game Model (RGM) has three core aspects player motivational type, game design patterns, and user behaviour types.*

2. APPLICATION OF THE RGM TO UPPER ARM STROKE REHABILITATION

Our RGM and initial online prototype tool was constructed over a six-month period and links core game mechanics from around three hundred game design patterns to core gamification types. An appropriately designed tool can embed much of the multi-disciplinary expert knowledge, logical processing and decision making required to support a less experienced team to make good design decisions. In this way rehabilitation games may be created that are more usable, user friendly, functional and fun, thus ensuring patients who will use it will be more motivated and more inclined to engage in regular, high quality rehabilitation. Our system extends the RGM to enable clinicians to input data and tailor system parameters based on patient requirements. This input is essential to establishing patient motivations and specific game mechanics, narrowing game ideas towards rehabilitation. For example, side effects or comorbidities that the game designer needs to take into account to create effective games for a given population and health condition. As well as the specific rehabilitation requirements, demographics factors such as age, gender and culture are also taken into account. In this way we can use available statistical population information to guide design guidance outcome from the tool.

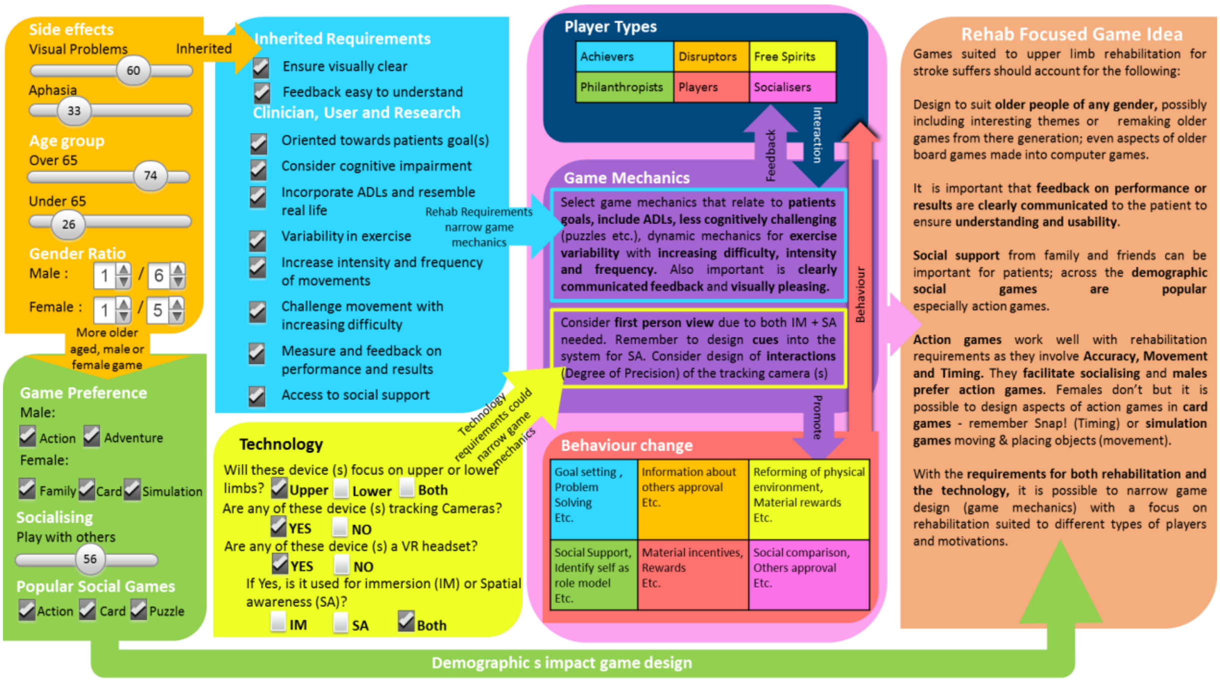

Figure 3: *Application of the Rehabilitation Game Model (RGM) to create an adapted serious game for upper limb stroke physical therapy.*

2.1 RGM Applied to Upper Limb Stroke Rehabilitation

The process proceeds as follows and may be implemented with an online tool or offline with guidance documentation:

1. *Key side effects following a stroke are identified*: For stroke we may consider ataxia, visual problems, spasticity, focus, thinking problems and aphasia. For example, aphasia is a communication disorder that results from damage or injury to language parts of the brain. Aphasia gets in the way of a person's ability to use or understand words (Lava 2014). These side effects create new requirements from upper limb rehabilitation.
2. *Stroke demographics are specified*: Statistics of people who have suffered a stroke, as well as age and gender. For example, typically people afflicted by a stroke tend to be from the older population and that there are almost identical numbers of men and women (Stroke Association 2016).
3. *Gamer demographics are identified*: Statistics of game players and how they might relate to the *stroke demographic* can influence the design of the game. For example the gender ratio from figure 3 shows little difference between the amount male and female stroke suffers, meaning that consideration needs to be taken to create game for both genders.

4. *Rehabilitation requirements*: Inherited requirements from the key side effects and requirement of clinicians, users and literature help refine the game mechanics from our RGM that are suitable for rehabilitation games.
5. *Technology requirements:* Different types of technology can produce different requirements to meet particular objectives in rehabilitation. It is important to remember these requirements just like rehabilitation requirements can influence game mechanics.
6. *Rehabilitation Focused Game Idea*: With all the requirements considered, the refinement of game mechanics narrow the amount of game design ideas possible allowing designers to create suitable games for upper limb rehabilitation. This gives clearer identification of player types and the typical behaviours that motivate the patients to keep playing. Game demographics should also be considered at this stage as it could impact the game design. The game genre "action" along with the socialising statistics, impact design because it relates greatly towards the rehabilitation requirements.

3. CONCLUSION

In this paper we have outlined our Rehabilitation Game Model and provided an illustration of its application to stroke rehabilitation. From this illustration, we can see a paper based or online tool embedding the RGM can aid the design process and safeguard against designer play preference or experience bias. It encourages the designer not to just consider the core physiotherapy requirements based on an average patient but take in consideration a wide range of factors and demographics. The approach supports experts (and non-experts) with different background to work effectively on the same rehabilitation game project, reducing project risks related to difficulty in communication. We are currently using this RGM online tool to design upper arm rehabilitation games for stroke survivors. This will enable us to evaluate the approach more fully. It is also our intention to develop the tool further to produce more detailed and rehabilitation focused game ideas, so that it can be made available online for other designers.

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Case study using virtual rehabilitation for a patient with fear of falling due to diabetic peripheral neuropathy

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ABSTRACT

The purpose of this case study is to report the effects of using virtual rehabilitation (VR) to facilitate improvement of gait stability and endurance in a patient recovering from diabetic neuropathy who also experienced fear of falling. Timed Up and Go (TUG) testing revealed objective improvements and the subject's gait appeared more stable and fluid. She reported increased confidence in walking and endorsed increased confidence on the Activity-specific Balance Confidence Scale (ABC). This study also establishes how VR games can be inexpensively made and tailored to specific therapy needs since games were made by undergraduate Computer Science students for credit.

1. INTRODUCTION

Diabetic peripheral neuropathy (DPN) can be a challenging illness to treat in physical therapy due to the combination of sensory and motor loss, neuropathic pain, and fatigue. Additionally, common comorbidities such as depression, anxiety, fear of falling, motivation, and executive dysfunction can also affect recovery. Skilled therapy providing safe repetitious exercises can both enhance motor recovery as well as provide adaptive strategies. People generally utilize a combination of somatosensory, vestibular, and visual systems to maintain balance (Wotseney & Joy, 1997). The loss of one of these systems places a greater burden on the remaining two systems. In this case study, the subject exhibited impaired sensory abilities and therefore, she had to rely more on her vestibular and visual systems to maintain her balance. This reliance on only two systems can be very challenging to therapists and patients, leading to increased fear of falling and ineffectual gait. While repetitious therapeutic exercises have been shown to facilitate recovery, fear of falling can greatly diminish a patient's motivation and effort. While still relatively a young field, VR is at the cutting edge of rehabilitation research. Recently, Zhen et al. (2016) performed a large meta-analysis with conclusions that support the use of VR to improve balance after stroke. However, few studies have examined the use of VR for those who have a fear of falling. Some of our previous research using the Wii Balance Board showed significant benefit over traditional therapies for those in pain (Ramchandani, 2008). It was thought that the engaging and diverting aspects of the games distracted the patients from their level of discomfort, allowing the subjects to stand and participate in therapy for longer periods of time with increased effort and engagement. Unfortunately, the Wii Balance Board system does not have the flexibility to be used with wheelchair users or those requiring assistive devices. Thus, we developed our own games which primarily image the torso, arms, and neck positions and are much less affected by assistive devices and can be used while seated.

2. METHODS

2.1 Subject

The subject was a 60 year old female with a history of hypertension and poorly controlled insulin-dependent diabetes mellitus who experienced an acute onset of DPN resulting in lower extremity pain, impaired lower extremity proprioception, and lower extremity diabetic amyotrophy characterized by weakness followed by wasting of pelvifemoral muscles. Over the course of her recovery, her motor abilities recovered at a faster pace than her sensory abilities. Prior to beginning physical therapy (PT), she primarily was using a wheelchair for transportation but was able to use a front wheeled walker (FFW) for short distances. Using the FWW, her gait was slow and deliberate, and she reported a fear of falling. She was participating in outpatient PT sessions and as an adjunct, she also participated in six sessions of VR.

2.2 *Hardware*

The Microsoft Kinect v1sensor 3d motion sensitive camera was used as the input device. The LiteGait® (Mobility Research), which was used only for her first session, is an adjustable weight bearing device in which the patient is harnessed for safe gait training.

2.3 *Software*

All games were created in the second author's facility and under his guidance. Games were designed with the input of physical and occupational therapists as to specific movement that would be beneficial. Games were made by senior level undergraduate Computer Science students as part of a senior project for partial class credit. SDL (Simple DirectMedia Layer) was used for sound and data was stored in MongoDB database, using JSON (JavaScript Object Notation). The web server was built using Flask and JavaScript and data was sent between game and server using secure shell (SSH) encryption.

2.4 *Games*

- *Coin Game*. This game was developed using Microsoft XNA Game Studio. In this game, a player guides a car along a roller coaster type track amassing coins and avoiding obstacles. The player manipulates the car with lateral leans to the right, middle, or center lanes. Leaning forward is used to duck below obstacles and leaning backwards is used to jump, allowing the therapist to address anterior/posterior as well as lateral balance. Auditory and visual cues such as arrows appear prior to an obstacle, thus requiring the player to attend to the signs as well as to the track. Coins are placed evenly on left and right sides of the track to elicit equal attention, and it is possible to view data afterwards to evaluate a player's movements.
- *Boat Game*. This game was developed using OGRE (Object-oriented Graphics Rendering Engine) for graphics and SDL was used for sound. The player guides a boat through a maze of icebergs in search of targets with forward and backward movements and left and right leaning. The player may lift either arm to shoot a laser beam at the target as can be seen in the left aspect of figure 1. This game can be used to challenge balance when arms are raised.
- *Plane Game*. This game was developed using OGRE for graphics and SDL for sound. A player moves their torso laterally to fly a plane while avoiding buildings and hitting targets as in the right aspect of Figure 1. As the game progresses, levels become increasingly faster and feedback includes number of targets hit.

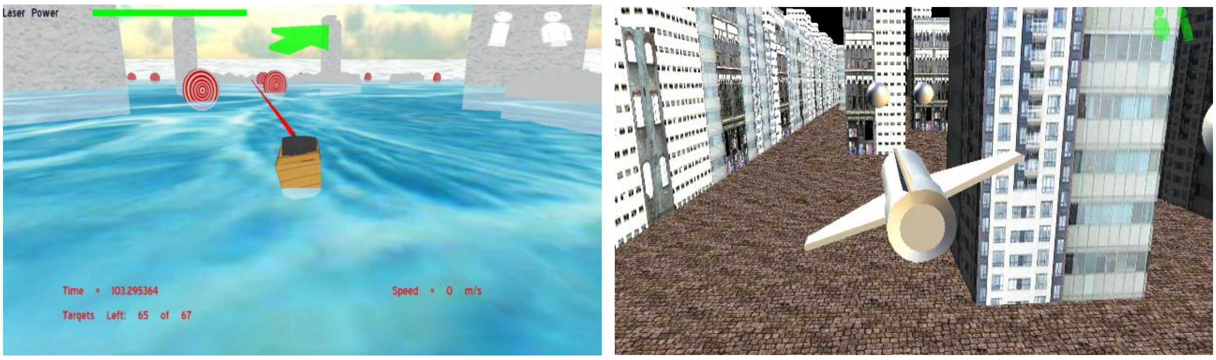

Figure 1. *Screen capture of Boat game (left) and Plane game (right).*

2.5 *Procedure*

The subject participated in six 45 minute long VR sessions with breaks provided as needed based on the subject's request or therapist's decision. Games were selected to address particular issues that the physical therapist wanted to address and the Plane, Coin, and Boat games were played on various sessions. During the first session, she was supported (but bearing her full weight) by the LiteGait device which was primarily used as a safety precaution and to increase her confidence. She was harnessed facing the Kinect sensor and bobby pins

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were used to hold down straps which would otherwise interfere with the sensor device. Halfway through this session the LiteGait was discontinued, and she used a FWW with her physical therapist guarding her. For following sessions, she used the FWW with diminishing reliance, and no assistive device was used on the final session. The TUG was assessed during the second session, before and after VR, with the subject using either a FWW or single point cane (SPC). The Activities-specific Balance Confidence (ABC) Scale (Powell, 1995) was administered prior to initiating physical therapy and at the end of treatment. The ABC is a self-rating measurement in which subjects rate their perceived confidence on 16 items such as their ability to walk down stairs, stand on a chair, or walk down a ramp.

3. RESULTS

3.1 Objective

This case study was non-planned, and data was analyzed retrospectively. As seen in Figure 2, the subject exhibited improvement in pre/post TUG testing using the FWW (24 seconds pre and 20 seconds post) and the SPC (31 seconds pre and 25 seconds post). She was also timed using no assistive device following VR at 26 seconds, but was unable to so before the VR session due to fear of falling and instability. While game scores were not recorded, her advancement in terms of increased game difficulty (such as increased speed of playing) also served as markers of her improvement. The subject also exhibited increasing standing and playing times over the course of the VR sessions. At the beginning of her starting treatment, chart notes reported that the subject was only able to walk for five minutes at a time and required a 30 minute rest break. For her final session, she was able to play for 45 minutes with no break. In terms of results of ABC evaluation, she reported increased confidence in her balance with an average 31.25% confidence while using a FWW prior to starting VR training and an average 85.3% confidence using no assistive device post VR training.

3.2 Subjective

The subject exhibited improved quality of her movements which were initially stiff and robotic-like but became smooth and fluid, and she moved in a faster manner over the course of her training. She exhibited one loss of balance during her first VR session (while in the LiteGait), but she was able to right herself. When asked about this experience after the session she reported, “I forgot to be scared.” At the beginning of the second VR session she reported, “I felt so much more confident and energized last session!” According to chart notes from that session, the subject exhibited “improved balance and decreased reliance on assistive devices after VR” and also noted that the subject moved faster and more confidently with improved balance.

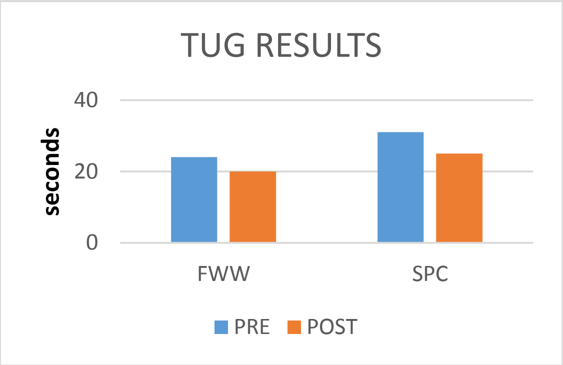

Figure 2. *Results of pre and post VR TUG testing in seconds*.

4. DISCUSSION

These results support that VR can be a useful adjunct to traditional PT, increase the engagement of the subject while providing repetitious therapeutic exercises, and help to increase balance confidence. Based on TUG testing, this subject’s speed of gait improved after VR training. While practice effects cannot be ruled out, the quality of her gait also improved, suggesting that VR contributed to her improvement. She also exhibited improved endurance with each session and completed successfully more challenging levels. Additionally, her realization during the games that she was able to lose and recover her balance seemed to be a significant boost to her confidence. Moreover, chart notes reported that the subject’s gait became “smooth and faster,” and the subject reported improved confidence and energy. Similar to Ramchandani’s (2008) theory that playing video games during therapy can be distracting from pain, we postulate that VR may have diverted the subject’s attention away from her fear of falling and improved her balance confidence. Additionally, this subject clearly enjoyed the games and perceived them as fun. This aspect, of course, is a central tenet to game theory which is that we are more likely to engage in activities we enjoy. This principle was central in designing our games. We attempt to incorporate therapeutic movements into a fun and engaging atmosphere. This positive distraction and competitive aspect are clearly important drives, and she consistently reported her desire to improve upon a previous score or level. The element that these games yield concrete scores for players to notice their improvement and set goals is also a central component of game theory, and we have previously shown how these aspects helped a stroke patient better appreciate his improvement (Carroll, 2016) as he was more trusting of improving game scores than his therapists reports of improvement.

Recently, Shema (2014) postulated that VR may help with the cognitive and motoric aspects of walking. For this study, 60 diverse subjects underwent VR training which consisted of walking on a treadmill while negotiating virtual obstacles. The authors postulated that VR differs from typical balance training, as it contains cognitive aspects of planning with constant adaptation and shifting of attention under varying motor conditions. While executive dysfunction is a more common comorbidity of diabetes, our subject exhibited no evidence of cognitive or executive dysfunction. However, there were substantial cognitive demands used in the games for this study in that the games required divided attention and multitasking (Coin game), spatial memory and upper extremity coordination (Boat game), and speed of processing (Plane game). It is interesting to consider that the cognitive aspects of our games may have also helped with her balance, and that engaging in challenging cognitive abilities during PT may be a useful therapeutic activity for those experiencing DPN. This study also demonstrates how VR games can be made inexpensively and tailored to specific therapy needs. These games were made by undergraduate Computer Science students receiving class credit for their projects. At the beginning of each class, therapists are consulted as to particular skills and movements that would be most beneficial to their patients. Various game scenarios are also discussed to ensure that the final product is both fun and therapeutic. To summarize, VR allows for multiple repetitions of desired movement that would be monotonous in more traditional therapies but can be achieved in a fun and novel way. The competitive aspects of playing games also increase motivation and provide concrete signs of improvement to further propel effort in therapy. Illnesses such as DPN may have complex and intersecting comorbidities such as difficult pain management, depression, anxiety, executive dysfunction and fear of falling which may impair a patient’s full benefit from therapy. The use of VR for these and other comorbidities may be a useful therapeutic endeavor.

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Application of invisible playground theory to assistive technology design for motivating exercise within activities of daily living

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ABSTRACT

Regular exercise promotes safe mobility for people affected by stroke, multiple sclerosis, and other disability related health conditions. It is also important for the prevention of falls among older people. Recent research investigates the use of indoor technology such as virtual reality (VR) and games to support and motivate regular exercise. Other research considers the use of mobile and wearable technology to track and promote exercise within the home and outdoors. In this paper we propose an approach that uses ideas from both contexts to develop a more persistent connected health system for encouraging more enduring exercise associated behaviour change. We utilise gameful design principles and play research to blend home-based VR and Serious Games with wearable, mobile tracking and reminder system approaches that are integrated into activities of daily living. In particular, we utilise ideas about the Invisible Playground from play theory to frame our interactive multi-modal exercise system. Our hypothesis is that by establishing a gamified, information rich feedback loop between structured system based exercise indoors and tracked activities of daily living outdoors, that motivation to exercise regularly may be improved. In this paper we summarise key relevant literature, discuss the Invisible Playground, and present the system architecture, APPRAISER, which will be used for the system development.

1. INTRODUCTION AND RELATED WORK

Promotion of exercise is important for maintaining and enhancing health after injuries or disabilities (Chao et al. 2013) and for older people to help prevent falls. Many people find motivation to sustain exercise and physical rehabilitation difficult (Uzor & Baillie, 2014) as it is often tough and not enjoyable. Games and virtual reality (VR) may be used to develop exergames or active games that help rehabilitation be more engaging and fun (Burke et al., 2009) and can be effective in the absence of physiotherapist supervision (Bateni, 2012). Traditional physiotherapist supervised rehabilitation continues to be the most effective way to administer high quality, directed physical therapy. However, it is important that people can be self-sufficient and self-manage their rehabilitation and so there has been increased focus on smart homes and on home automation (Chan et al, 2009). Creating adaptive rehabilitation systems to encourage positive user behaviour at home is one approach (Leonardi et al., 2009). Smartphones have been recently been widely used in experiments focused on people's activities of daily living (ADLs) outside the home (Brunnberg et al, 2009) due to their inherent tracking capability using built-in GPS, accelerometer or gyroscope capabilities. In commercial applications, there are a range of social games that have been designed to encourage people to be collectively active. GeoCaching apps encourage people to go to real location in the real world to attain objective or collect "treasure" and games such as Ingress (Niantic, 2014) overlay an actual videogame. Active tracking apps such as Runtastic (Runtastic, 2016) or Strava (Strava, 2014) blend sociability with game design features to build active communities. Thus technology has great potential to bring people together to engage in a physical activity. In this paper we outline an approach to motivating exercise, influenced by the Invisible Playground (Salen & Zimmerman, 2005) from digital game theory, which seeks to bridge the gap between indoor situated exercise and ADLs. A serious game underlies the approach which be more persistent and be less bounded than existing approaches.

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2. MOTIVATING EXERCISE IN THE INVISIBLE PLAYGROUND

Serious games for rehabilitation are typically based indoors and often do not integrate social factors that provide crucial communal enjoyment. Games can be designed to include social communication features and for example may provide competitive and cooperative gameplay offline or across the internet. Though social interaction online can improve enjoyment within interactive software it is generally more satisfying for people to engage with other people in the real world outside the home. The system that we propose uses games and VR technology in the home to improve fitness and confidence to exercise outdoors, while also gamifying ADLs. We consider ideas from digital games research on the Invisible Playground, previously applied to commercial game design and educational games (Charles & McAlister, 2004) and relate the theory to the design of serious games in an assistive health technology context. The fundamental idea of the Invisible Playground is that modern games are not bounded by the "Magic Circle", (Huizinga, 1971) but rather overflow from the virtual out into everyday life and embedded into culture (Figure 1). In simple terms we consider the application of the Invisible Playground to a health context by creating a game which is persistent, with gameplay mechanics fitted to location, technology and circumstance.

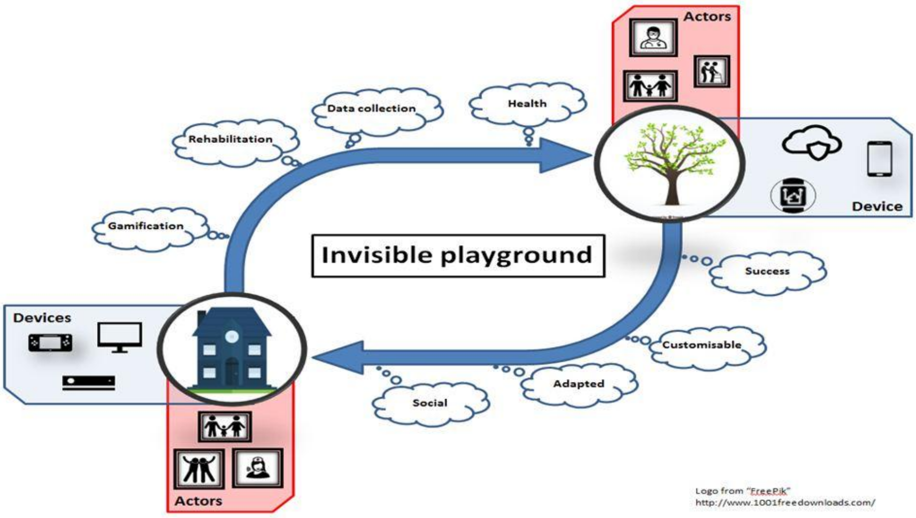

Figure 1. *Illustration of the Invisible Playground showing the closed loop between indoors and outside.*

In home games VR hardware systems (e.g. Omni Treadmill, HTC Vive, Kinect, and Leap Motion) may be used to tailor specific and safe exercise programmes while wearable trackers (e.g. Moov, Withings, or Fitbit) may be used paired with Smartphone technology to continue the game in ADLs. The main idea is that indoor game based health technology activities can motivate and encourage transfer of exercise to everyday activities and vice versa. Indoor games and VR provide supportive and directed programmes of activity with built-in challenge-reward schemes, adaptive difficulty, and personalised activities schemes. Tracker systems based around wearable, smartphone technology, and gamification design can enable the "game" to continue around the house and within the community; providing additional challenge-reward scenarios based on location and motion tracking. On return to the home, logging back into the home based system allows the user to collect rewards and view fitness and achievement profiles – so establishing a feedback loop between virtual and real world exercise, between the home and outdoors. It is this closed loop system at the heart of our proposed approach that we believe can be more effective in providing sustained engagement with exercise and potentially more enduring behaviour change than with other approaches. The approach requires thoughtful gameful design across modalities.

To facilitate development of a rehabilitation system based on the Invisible Playground principles we created the APPRAISER component architecture (Figure 2). In essence APPRAISER is a connected health architecture and contains what we consider to be all of the required components for effective Invisible Playground system design and development: models of person's physical ***A**bility*, ***P**ersonality* type, personal ***P**references*, and embedding of specific rehabilitation ***R**equirements*, so the system can be effective in ***A**dapting* to individuals. Internet-based services via computers (indoors) and smart devices (outdoors) facilitate enriched social ***I**nvolvement* and access to clinical Support to improve ***E**ngagement* with exercise and ***R**ealise* goals through forming positive habits. State-of-the-art technology monitors, records and facilitates dynamic interaction with users based on personalised models and network connectivity supports clinical and social interaction. APPRAISER uses our rehabilitation game model (RGM) (Holmes, Charles, Morrow, McClean, & McDonough, 2015). The RGM was developed to guide the design of rehabilitation games on the basis of an extensive catalogue of game design patterns, gamification principles, and core behaviour change techniques.

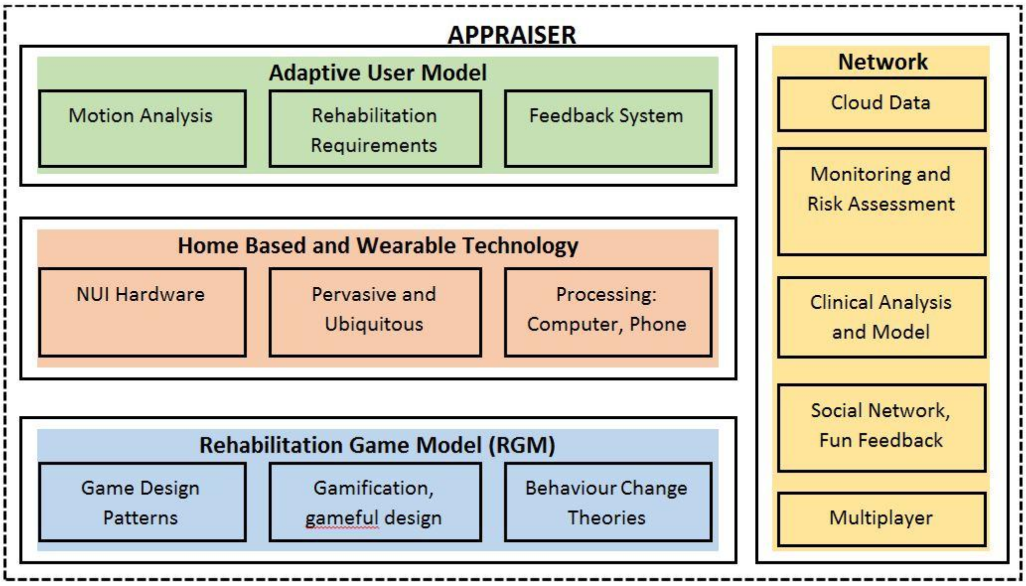

Figure 2. *The APPRAISER architecture comprises four core components*

Our initial experimental focus, currently ongoing, is focused on rehabilitation methods for fall prevention and gait improvement and considers the application of OTAGO and FaME for fall prevention (Gawler & Hanna, 2011), multiple sclerosis and stroke rehabilitation (Batchelor et al, 2012). Figure 3 provides an illustration of our first game design to implement the Invisible Playground, blending fixed location game based exercise and gamified daily life. Ideally, the "game" will be as non-intrusive as possible but will enable people to integrate exercise related fun activities into ADLs. The game illustrated in Figure 3 is a version of the classic "capture the flag" game, where locations surrounding a person's home are partitioned into areas that may be captured by physically visiting them. There will also be other classic gameplay elements outdoors such as treasure hunts and puzzle solving – tied to tracking and reminder systems which offer tailored exercise opportunities (such as structured arm or leg movement). In this game instance the person's home acts as a kind of "base" to which items are brought back for selling or bartering at a store. In the base people can view player statistics, tailor their inventory for outdoor quests and conquests and can improve their (player character's) attributes by performing actual physical exercise. There are many other potential gameplay elements but these examples serve to illustrate how the gameplay is designed to maintain a closed loop gaming system between indoor and outdoor activity.

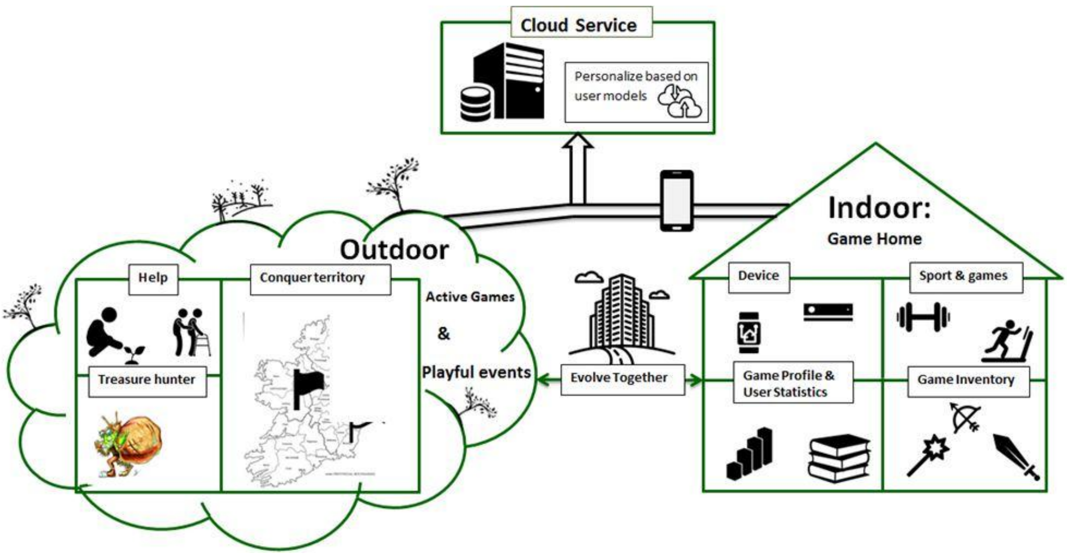

Figure 3. *Real life implementation of Invisible Playground theory.*

3. CONCLUSION

We have proposed using an Invisible Playground design principle to integrate rehabilitation exercises into activities of daily living and discussed implementation in practice. The main benefit of the proposed approach over existing methods is that we explicitly link fixed location exercise or rehabilitation to activities of daily life. Date from physical activity monitoring using smart technology will facilitate modelling and the categorisation of user motion, which will form the basis of reminder, feedback and reward systems. Our hypothesis is that we could improve transference and potentially improve function. We have currently created a Kinect based exercise system for indoors which integrates the Otago fall's prevention programme, and we will move on to build the tracking and reminder game systems for outdoors, then the underlying game and gamification systems. It is our intention to conduct a trial to investigate the acceptance of technology and the effectiveness of gamification in the invisible playground context. We are interested in find out whether the invisible playground improves health conditions and behavioural attitudes to sustainable regular exercise.

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Visual elements influence on navigation in virtual environments

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ABSTRACT

Virtual rehabilitation often incorporates an element of travel in a virtual environment. Whether patients are transported automatically through the environment, or whether they have navigational control, it is important to understand how the design of the environment itself can supply navigational cues, and how the processing of these cues may influence perception, behaviour and task performance. This paper explores the literature, which might inform application design, and presents a case study using a think-aloud protocol to explore the perception of users to visual cues within a running game. We conclude with some preliminary suggestions for positive and negative navigational cues.

1. INTRODUCTION

Virtual rehabilitation often involves navigating through a virtual environment while performing the rehabilitation tasks. It is often necessary to guide or influence the patient's navigation direction, to lead them towards a specific point, to limit exploration of a finite environment, or to redirect their movements within the real world space.

However currently there is little known on why and how people make choices when navigating within a virtual environment. Navigational studies commonly explore participant's memory of a route, focusing on landmarks, routes and layout of an environment (Van der Ham et al., 2015), rather than their dynamic response to perceptual cues. Vasylevska et al. (2013) created an application to test participants' responses to perceptual cues. They designed a building that could be explored by the users without any instructions. The corridor would then change its features and content when a room was entered. The changes proved to be unnoticed by users, but require modifications. This suggests that by obscuring the user's sense of direction, participants experience a sense of being lost due to a lack of orientation aids in virtual environments (Vasylevska et al. 2013). Redirecting participants in different directions, in order to believe that they are in a larger space suggests that certain navigational cues are not being entirely considered by the participants explaining why they were feeling lost (Vasylevska et al. 2013). Therefore, there is a need to better understand the influence of navigational cues in a virtual environment.

Improving our understanding of user's responses to visual cues may influence navigational choices and would allow us to provide conscious or unconscious navigational aids within virtual rehabilitation applications. This would enable a patient to be guided around a virtual environment whilst creating a sense of navigational control, and could also avoid inadvertently adding to their cognitive load.

2. REACHING A TARGET LOCATION FROM THE CURRENT LOCATION

Wayfinding is the term used to describe the spatial problem solving of reaching a target location from the current location. In the context of this research, we use Emo (2014) definition of wayfinding, where wayfinding is defined as cognitive approach to a task, based upon visual perceptions in the environment. In order to explore participant perception and how visual cues may influence people to make certain navigational choices, it will be important to have an understanding of the components of wayfinding.

Effective wayfinding may use elements of location identity, landmarks, orientation cues, well-structured paths, and visually distinctive regions, as well as survey views, signs and sight lines (Foltz, 1998). Additionally, navigational aids can include 'lighting', 'architectural design', 'reference objects' and 'audio and olfactory cues' (Lee and Kline 2011; Bowman 2004).

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Most of the research on wayfinding relates to interactions with keyboard, mouse or joystick, and less is known about how these cues are perceived during more active interactions. This paper presents a pilot study exploring how users perceive visual cues whilst running-in-place through a virtual environment.

3. PILOT STUDY

The aim of this research is to investigate conscious navigational aids presented within an environment. A pilot study was used to address participant's perception of applications when travelling through an environment, which does not allow for a choice in navigation. This will help to understand how a patient could travel through an environment whilst creating a sense of navigational control, but also to increase any unnecessary cognitive load.

For this pilot study, we opted to explore the perception of participants travelling along a route which did not allow them navigation choices, using the 'Wii-Fit running mini game'. This game features a populated open environment, with a structured path where the character follows the guide, along an animated path.

During the study, we followed a 'think aloud' protocol. The 'think aloud' protocol allows participants to verbalise their opinion during the pilot study. This method is appropriate to observe participants, without the bias of prompting participants to say what is expected of them. This will allow a basic understanding of user's responses to visual cues, which may influence their choices in navigation.

Four adults participated in the study: three male and one female, age ranging from 21 to 44 years old and an average age of 32 years old. The participants were familiarized with the equipment and how a 'think aloud' protocol works. They were then given a Wii-remote and stood in front of a television. There were cameras positioned behind, in front and to the side of each participant, to capture any data surrounding body movements.

At the end of the pilot study, a short interview was conducted asking the following questions in order to prompt any extra data from the participants: '*Did you find yourself at any point wanting to travel somewhere else?*', if so '*What specifically made you want to go in another direction?*' and '*How did travelling through the environment feel?'* The questions were designed to be open ended to not push participants to what they deem is an appropriate answer, but to create a basic understanding of user's responses to visual cues, which may have influence their choices in navigation.

4. RESULTS AND DISCUSSIONS

The study was used to create a basic understanding of user's responses to visual cues, to see how an environment that contains no navigational control may influence choices in navigation within predefined populations. Participant's perception of the environment altered throughout, for different reasons (see Table 1 for more details).

When prompted by the user interface, to change pace when travelling through the environment, participants either experienced deflation, or disappointment, as a result of the pace suggested not meeting the user's expectations. In virtual rehabilitation it would make sense that participants should feel a sense of control of their own pace as this could hinder the process of achieving their therapeutic goals.

Participants one and two started moving forward in the physical world, when approaching a fork in the path in the virtual world, perhaps subconsciously having made a choice in navigation. Two participants that took the longest to travel through the environment, noted the majority of navigational cues within the virtual environment. It may suggest that patients need busier environments with enough to focus their attention on, as the participants who travel faster notice fewer navigational cues. This needs to be considered within the design of virtual rehabilitation applications if patients need to see the cues.

There are certain suggestions on how to subliminally guide people in certain directions, by redirecting participant's attention to areas of interest. It can be suggested that visual cues need to blend well into the environment, perhaps by using colour coding in order to help navigate participants (Madigan, 2013). If visual cues are subliminally implemented into the design of virtual environments, this could lead to 'inattentional blindness'. This is a daily subconscious occurrence when certain situations are not noticed, as their attention is associated with something else at the time. It occurs because only a small percentage of conscious perception occurs at a given moment as a result of senses becoming overwhelmed (Green, 2013). Therefore, if a virtual environment is to be designed with influencing choices while still having a sense of openness for participants in virtual rehabilitation it will be important to consider 'inattentional blindness'.

Participant three has attention deficit hyperactivity disorder (ADHD), which may explain why they appeared more concerned with finishing the race rather than commenting on usability as instructed. It is important to acknowledge that this pilot study was to generate a basic understanding of participant's perception of navigational cues, highlighted from literature, so there was little concern about demographics at this current stage of researching. However, as virtual rehabilitation is being adopted for clinical treatment of ADHD (Yeh et al. 2012) it is important to consider the behaviour of participants that have ADHD, as this might affect design considerations when influencing direction of travel.

Table 1. *Summarized key visual elements that were commented upon from the pilot study.*

Navigational cue	Participant One Reaction	Participant Two Reaction	Participant Three Reaction	Participant Four Reaction
Structured Path	Became bored with the path as they no longer wanted to follow everyone else.	Did not have any desire to not follow the path.	Did not have any desire to not follow the path.	Did not have any desire to not follow the path.
Small Natural Tunnel	Found the small natural tunnel fun, commented that the shadow created made them cooler.	Knew they were heading towards the tunnel, mentioning the shade, but expressed no feelings.	Knew they were heading towards the tunnel, but expressed no feelings.	Knew they were heading towards the tunnel, but expressed no feelings.
Grass	Felt compelled to run along the grass	No Reaction	No Reaction	No Reaction
Characters	Kept saying hello, and interacting with the characters by waving back. Did not enjoy being overtaken by others. Found the dogs cute.	Did not enjoy being overtaken by other runners or the dogs. Initially bemused with the waving, and physically moved backwards. Later enjoyed the characters waving and felt it became a friendly atmosphere.	Commented on other characters without showing any perception but acknowledged they were in the environment.	Commented on other characters without showing any perception but acknowledged they were in the environment.
Guide	Wanted to get past the guide within the environment.	No longer wanted to follow the same guide, wanted a different one to follow.	Was frustrated with the guide being faster, and became more and more competitive throughout.	Was frustrated with the guide being faster, and became competitive.
Change of Pace	Expected to go faster downhill, as a result became deflated.	Was happy when overtaking someone, as they commented that they were frequently trying to increase speed.	Was disappointed that they would be punished for going faster, as the character would trip as a result.	Was frustrated that the interface told them to slow down and not speed up.
Fork in the path	Sped up upon approach.	Sped up upon approach.	No reaction.	No reaction.

The main key findings of the study are:

- Participants frequently commented upon the characters in the environment.
- All participants became frustrated at the change in pace throughout the environment, not allowing them to travel at their speed, or not doing what they expected to occur.
- All participants commented on a small natural tunnel present within the environment through which the participants had to travel, and the shadow it cast.
- Majority had no desire to leave the structured path.
- All participants commented upon the environment's landmarks by expressing their feelings and perceptions.

5. CONCLUSIONS

Conducting the pilot study was beneficial. It highlighted inattentional blindness, as an important psychological consideration, as well as behaviour alterations when presented with certain navigational aids, some of which were visual. It also shows that the participants become frustrated when not allowed to control their own speed. A well-structured path may prove beneficial in order to influence their choice, yet may not lead to the openness of an environment that would be beneficial for rehabilitation. Therefore subtle navigational cues will be important to influence participants' navigational choices by association of elements such as colour. Overall it seems possible to influence the direction of travel, to help achieve therapeutic goals while allowing for an open world. However, further work will need to be carried out to validate the results.

During the pilot study, participants commented upon: 'Landmarks and Artificial Landmarks', 'User interface, with relation to maps', 'lighting', 'Colour and Atmospheric effects' and 'Signs'. Therefore the choices presented in Table 2 can be extracted as reassuring or discouraging cues.

Table 1: *Possible navigational cues for future study.*

Reassuring Navigational Cue	Discouraging Navigational Cue
Main Street	Alleyway
Illuminated	Shadowed
Good Condition (Clean, well looked after etc.)	Bad Condition (Messy, destroyed etc.)
Free Path (Without Obstacles)	Obstructed path (With obstacles)
Sun	Rain
Populated	Unpopulated
Downhill	Uphill
Bright Colours	Dull Colours

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Development of a low-cost upper limb rehabilitation system using BCI, eye-tracking and direct visual feedback

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ABSTRACT

We are developing a novel system to improve arm function in stroke patients who have no, or only residual upper limb movement. Such a system fills an important gap in treatment options for people with little-to-no upper limb movement after stroke, and for whom regular treatments often are unsuitable. The system provides real-time visual and proprioceptive feedback of the arm plus the ability for participants to steer the movement direction of the arm through an assistive movement platform. The patient controls the system by simply looking at stimuli and engaging in motor imagery. The patient gaze is monitored with an eye tracker and motor output intentions are monitored with an EEG-based brain computer interface. Stimuli are presented as games in order to create a motivating rehabilitation environment. In this paper we discuss our motivation and design of the system.

1. INTRODUCTION

Stroke is a leading cause of severe disabilities and death worldwide. The number of stroke sufferers and the associated financial costs will increase with an ageing population and the growing incidence of obesity and diabetes. Because there is no cure for stroke, the only method to improve functional movement is through rehabilitation. Approximately 30% of stroke survivors require rehabilitation to regain function. The main mechanism in motor rehabilitation is enhancing the activity of the primary motor cortex, as induced for instance by Active Motor Training (AMT). While effective, current rehabilitation approaches have certain limitations:

- Severely paralysed patients have difficulties using AMT. The patients require at least residual motor performance in the affected limb in order to engage in AMT.
- It is difficult to achieve the high numbers of repetitions necessary for rehabilitation to take effect, and challenging to sustain the patient's motivation in the highly repetitive and monotonous exercises.
- These exercises often require the continuous presence of a physiotherapist or occupational therapist helping the patient to perform the motor exercises. Conventional rehabilitation is very labour intensive and there are considerable costs associated with therapists engaging continuously with the patient during the rehabilitation exercises.
- There is a lack of immediate feedback to the patient.

Combining robotics-assisted rehabilitation with Brain Computer Interfaces (BCI) is a promising way forward. A BCI is a system that monitors brain activity (with electroencephalography (EEG) for example), which is analysed and then used as system input. Movement intent and motor imagery are generally not affected by stroke

Proc. 11th Intl Conf. Disability, Virtual Reality & Associated Technologies
Los Angeles, California, USA, 20–22 Sept. 2016
 ISBN 978-0-7049-1547-3

(Ang & Guan, 2013). Hence, movement intent can serve as a substitute for AMT as a means to activate the motor cortex (and/or adjacent areas) and to control a BCI.

2. RELATED WORK

BCIs based on movement intent have previously been found to be effective for motor rehabilitation in stroke patients (Ang et al., 2011)(Ang & Guan, 2013)(Daly & Huggins, 2015). Repetitive exposure to a motor imagery EEG-based BCI can affect brain plasticity and induce persistent functional changes in the motor cortex. Pichiorri et al. (Pichiorri et al., 2011) found functional changes in the motor cortex in a group of people undergoing motor-imagery based BCI training. A key aspect of our project is that using a robotics-based BCI to assist with the movement of a person's arm once movement intent has been detected, allows stroke survivors to see and feel their arm moving as they intended and may engage not only the motor cortex of the patient but also adjacent areas in the neocortex such as the sensory cortex. This could play a critical role in the rehabilitation of the neural network engaged in motor control and therefore contribute to improving rehabilitation outcomes.

McCabe et al. (McCabe, Monkiewicz, Holcomb, Pundik, & Daly, 2015) compared treatment outcomes from non-technology assisted motor learning (ML) to ML plus robotics, and ML plus functional electrical stimulation. In a randomised controlled trial all group significantly improved but the authors did not find a significant difference between the three treatment groups.

Many repetitions are required for neuroplasticity to take effect (Verghese et al., 2014). Technology assisted rehabilitation can free up highly specialised therapists and provide patients with long and motivating treatment sessions. This can result in considerable cost savings. Lo et al. (Lo et al., 2010) conducted a cost analysis and found robotics-assisted therapy to be comparable to personal therapy. As general costs of technology tend to decrease and labour costs tend to increase over time, the cost-benefit relationship of technology-assisted therapy most likely will improve as well.

3. SYSTEM DESIGN

3.1 System overview

We are extending previous work by designing a novel combination of technologies that has the potential to increase the system's accuracy, its performance, and to improve feedback to the patient. We are developing an integrated assistive rehabilitation system that uses a patient's gaze fixation to inform the system about the location where the patient intends to move to, uses motor imagery-based BCI to detect movement intent, and employs a mechanical-robotic platform to assist with the movement of the patient's arm to the target location. This system provides a means for automated and assisted high-volume rehabilitation, with simultaneous real-time proprioceptive and visual feedback, even for those with minimal or no residual motor ability.

By combining visual (screen) and movement feedback into a shared reference frame, the patient can see his / her hand moving, while viewing the virtual stimuli at the same time. Most other systems present visual stimuli on a screen at eye level, separated from the actual hand. Our system features stimuli being presented on a screen underneath the patient's moving hand.

The system integrates new interaction paradigms for steering the movement platform. The patient can steer the platform and hence their upper limb to a specific location by simply looking at that location. To achieve this an eye-tracker translates the user's gaze fixation on the screen into x/y coordinates for the target location. This is similar to Frisoli et al. (Frisoli et al., 2012), who have presented a complex system that combines gaze and BCI control of an exoskeleton. In addition to using eye-gaze tracking for target acquisition, we use the eye-gaze as an input for multimodal signal processing which allows for enhanced BCI accuracy. Through combining gaze fixation with the information form the EEG signal we can improve the accuracy of detecting movement intent. In previous work we have shown how combining other eye-gaze parameters (such as real-time changes in pupil dilatation) with the EEG signal can improve BCI accuracy (Rozado, Duenser, & Howell, 2015).

For the collection and time synchronisation of the EEG signals, gaze tracking data and visual stimuli, we use the open source library Lab Streaming Layer (LSL). LSL provides a built-in time synchronisation functionality for recording psycho-physiology data that is designed to achieve sub-millisecond accuracy on a local computer network. Essentially, every collected sample (from the EEG amplifier, gaze tracker or visual stimuli engine) is associated with a timestamp, read off a clock source whose synchronisation is handled by LSL at the time of submission from the device driver to the LSL.

3.2 The prototype system

Our assistive rehabilitation system incorporates a horizontal x-y motion platform. We have developed an orthogonal ball screw and linear bearing arrangement to enable movement over the full extent of a 40″ LED screen. This low-cost platform can move a person's arm in two degrees of freedom, using one motor per axis to drive a ball screw. The speed and acceleration of each axis is coordinated using proprietary software. Users rest their affected limb on a cradle / wrist guard that is magnetically attached (for easy de-/coupling). This assembly sits on a rod that connects to the movement mechanism at the back of the platform (this setup places the moving parts away from the user). The LED screen presents visual stimuli, ranging from a simple set of static objects that the patient has to reach for (e.g. moving the hand to the location of a cup displayed on the screen) to more complex and motivating games.

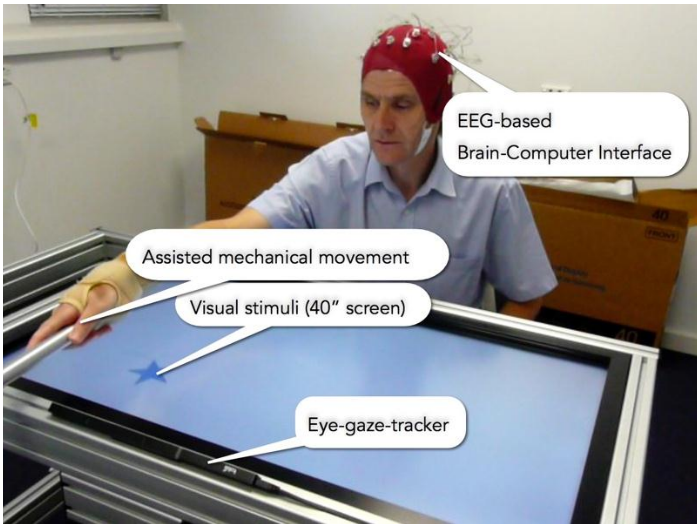

Figure 1. *System prototype*.

The system locates the patient's gaze fixation (a particular position being looked at) via an eye tracker (Tobii Eye X). If the gaze position correlates with a presented stimulus, and motor intent to move the upper limb is detected by the BCI, the robotic system assists in moving the patient's hand to the gaze position. We use a BioSemi ActiveTwo electroencephalography (EEG) amplifier with 32 channels to measure scalp potential, the BCILab library (Kothe & Makeig, 2013) for detecting motor imagery, and the Lab Streaming Layer library for networking, data collation and time synchronisation for EEG and gaze time series streams. An in-house developed software package provides stimulus presentation, trial execution, trial analysis and outputs for controlling the robotics system. (A video showing the functionality the prototype is available on Youtube: http://tinyurl.com/BCI-rehab).

While the combination of eye-gaze tracking and BCI is the main operating mode is for our system, other means of interaction can be integrated in future development iterations. This may include other ways to trigger or initiate movements such as physical switches, voice commands, facial gestures, or other sensors such as EMG, force or positions sensors that can detect even slight movements by the patients. In addition to affording other ways to interact with the system, these sensors also could be used to interactively monitor and measure movements and provide progress feedback to patients and therapists.

To address problems with monotony associated with having to perform highly repetitive movements, we use games to improve patient motivation. For this we are collaborating with serious gaming experts, who have developed unique game concepts for this platform. These games are based on traditional game concepts but have been adapted to suit the platform and target audience. Due to the design of the platform, there are some constraints for game and interaction design ranging from game pace and range of motion (which varies between individuals and may change as a consequence of the intervention) to occlusion of the eye tracker by the patient's hand. We anticipate that the systematic implementation of suitable game elements and reward systems can promote compliance with therapy regimens.

4. CONCLUSIONS

We present here a technical summary of our work-in-progress on a robotics-assisted BCI-based platform for upper limb rehabilitation. Our implementation is novel in that it allows the patient's limb and the visual component of the technology to exist in the same reference frame, thus potentially enhancing the effectiveness of assisted rehabilitation. Combining visual stimuli and feedback as well as proprioceptive feedback may have unique benefits compared to previous implementations that mostly separate task and feedback spaces.

We use eye tracking to drive the positional movements of the assistive movement platform and as a means to improve the detection of movement intention. Combining information sources, in this case eye-gaze fixation on a target stimulus and an EEG-based BCI that detects a patient's intention to move, has the potential to improve detection accuracy compared to previous embodiments of similar systems.

Future work on this project will aim towards continually improving the detection and classification of EEG signals, with particular focus on the asynchronous detection of signals. Furthermore, we will continue our research into multimodal signal processing, combining a variety of psychophysiological signals, to improve the detection of movement intent.

Finally, we are in planning stages of a study to test the feasibility of the developed approaches with 10 stroke patients.

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Human cognitive enhancement tested in virtual city environments

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ABSTRACT

The presented study focuses on human cognitive enhancement (HCE). Our aim is to map the key moments in interfacing of biology and technology that have the capacity to strongly affect and transform cognitive processes, such as spatial memory and navigation. We hypothesize that long-term use of HCE technology, in our case Augmented Reality (AR) glasses, while navigating through real environment can elicit changes both in spatial memory performance and in brain activity, connectivity and morphology. The proposed experiment focuses on the effect of long-term use (10-12 weeks) of Smart glasses (Vuzix M100). We tested 25 healthy volunteers, who were required to use the Vuzix navigation software when navigating in daily life. Prior to the experiment and during the final 12th week all participants (25 experimental and 25 control subjects) underwent complex prospective evaluation. The following test battery was used in order to study the effect of AR glasses wearing on: 1) vision (Ophthalmology examination); 2) cognitive abilities (RBANS, CPT, TMT); 3) specific spatial abilities (e.g. Money Road Map test, Perspective Taking Test); 4) eye-movements (eye-tracking) in the route-following and way-finding navigation performance in complex virtual city environment; and 5) brain activity (fMRI navigation task in virtual city, resting state fMRI) and morphology (VBM, DTI).

1. INTRODUCTION

Emerging technologies have immense impact on human life. Advances in technologies have allowed for unprecedented modifications of human bodies and our cognitive capabilities, pushing the field of Human Enhancement (HE) far beyond the state imaginable just a couple of decades ago. This fast development leads to rapid paradigmatic shifts in the concept of human self, interpersonal relations, and ethical issues (Sandberg, 2013; Bostrom and Savulescu, 2009). In order to maximize the benefits of HE devices and eliminate their risks and detrimental effects, emerging technologies must be actively addressed. HE-like interventions can be divided into three categories: “negative”, aimed at curing a disease or eliminating a disability; “positive”, improving the functioning of an organism within the natural range; and “enhancement”, taking an individual beyond natural functioning (Tännsjö, 2009). The acceptance of a HE device strongly depends on which of these categories it belongs to, with the “negative” interventions being the most acceptable. The key aspect of HE acceptance (individual, social, cultural), however, seems to be its naturalness (Bostrom and Savulescu, 2009).

This study aims specifically at human cognitive enhancement (HCE), a sub-field of HE addressing interventions into human cognitive capabilities and processes. Corporeal enhancement have already been widely studied (e.g. as a part of ethics of sport, cyberculture studies, gaming industry, medical rehabilitation practices, robotic, etc.), whereas cognitive enhancement is a newly emerging scientific field due to its dependency on cutting-edge technological developments. Even though this study focuses on HCE, selected aspects of corporeal enhancement will be incorporated as well. Thus, we will be able to map the key moments in couplings of the biological and technological i.e. natural and artificial, interfaces which have the capacity to strongly affect and transform cognitive processes. These is examined and discussed in the context of cognitive enhancement by AR glasses technology. We formulate the following hypothesis: long-term use of AR glasses while navigating through real environments can elicit changes in spatial navigation abilities and in brain activity and morphology. Such changes could be similar to those observed in expert taxi drivers, where the grey matter volume changes of hippocampus were correlated with increased navigation performance (Maguire et al, 2006). In contrary, GPS-like navigation could negatively affect volunteers' wayfinding abilities (Hartley et al, 2003; ; Ishikawa et al, 2008; Willis et al, 2009), as proposed e.g. by Eleanore Maguire (public press articles).

The project is conducted in two phases:

1. We conducted large-scale online survey addressing several topics in order to: a) understand the relationship between the acceptance of HE technologies and the personality (Big Five NEO-PI-R and Cloninger's Temperament and Character Inventory -TCI), self-acceptance and personal ethical concepts; b) identify demographic and personality types with low or high acceptance towards HE and HCE technologies.
2. We also carried out prospective evaluation of cognitive abilities, spatial navigation in virtual environment and in the field, and brain activity and morphology in a small group of participants selected from the previous large-scale survey using the following criteria: healthy volunteers with no history of physical or psychiatric illness, 18-55 years old, motivated in participation, with normal or corrected vision, meeting the conditions for MR scanning. Please note that this phase is currently in progress.

2. METHODS

2.1 Subjects and design of the study

In total, twenty-five healthy participants (experimental group) are tested in two sessions, first prior to the experimental study (TEST session) and after 10-12 weeks of using the AR glasses (RETEST). Another group of 25 participants (control group) is tested in the same repeated design, but without any external HCE device. Prior to the experiment all participants are asked to rate their own navigation abilities (similar to school grade) and to report about their previous VR gaming and GPS-like device usage experiences. These ratings will be used as one of the factors affecting their navigation in the VR city test.

2.2 Apparatus and study design

Augmented Reality (AR) glasses Vuzix M100 Smart Glasses (see Figure 1), presents the HCE emerging technology tested in our study. The participants are asked to use the incorporated GPS application (using OsmAnd map sources) for navigation in real world for a period of 10-12 weeks (min 3 hours/week). Participants have to report their evaluation of the device usage every two weeks via standardized user experience survey and subjective experience survey in order to address the usage patterns and mechanism of individual coupling with the device. The duration of active usage of the device is logged automatically via an incorporated application.

The following test battery is administered to all participants:

2.2.1 Eye examination. All participants undergo standard Eye examination extended by several extra measurement techniques in order to analyse possible physiological effect of the AR glasses on the sight of the participants. Possible changes in vision can be related to the following reasons: repeated changing of focus from the display (appears to be 3 m in distance) and the real environment, device camera obscures the FOV of one eye during 10 weeks of usage etc., for details see the online report by Sabelman and Lam (2015).

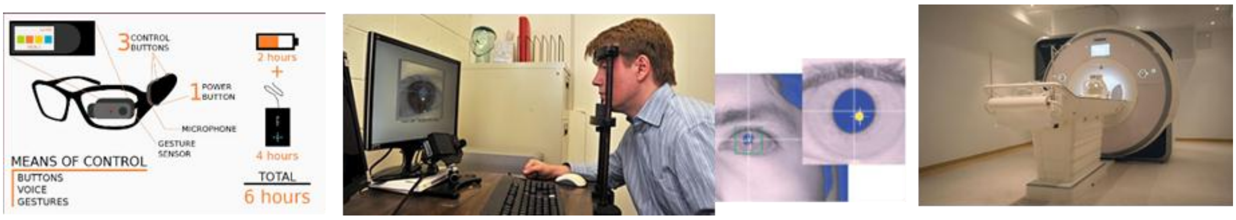

Figure 1. *(left) The HCE device Vuzix M100 Smart Glasses; (middle) eye-tracking device Eyelink 1000 with Head Supported and camera view; (right)3T Siemens Prisma MRI scanner.*

2.2.2 Neuropsychological and Quality of life evaluation. Cognitive abilities are assessed using the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS), Cognitive Performance test (CPT, PEBL battery) and the Trail Making test TMT. Two other methods will be used to address specific spatial abilities such as left-right mental rotations (Money Road Map test, RMT) and perspective taking abilities (Perspective Taking Test). The WHOQOL-BREF questionnaire is used to address the issue of quality of life (QOL).

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2.2.3 Eye-tracking experiment. The eye-tracking device Eyelink 1000 (see Figure 1) is used in the experiment with a chin and forehead rest (Head Supported settings). The design of this device makes it possible to be used during navigation experiments in complex virtual city environment.

Effects of long-term AR glasses wearing on navigation performance is currently tested in the Virtual city test. The virtual city environment was developed using the Unity game engine software (https://unity3d.com/). Each trial starts with the teleportation to a start location. Individual trials require the participant to navigate using a map of the environment in two conditions (presented in Figure 1), either with marked trajectory (route following, learning trial) or without it (wayfinding, recall trial). Participants visit 42 virtual city places (such as hospital, university, museum etc.) in total. Pairs of two places (21 duplets in total) are tested in two conditions: A) *route following* and B) *wayfinding*. Small schematic map of a city section where the participant is currently walking is presented in the left corner to all participants during both conditions (see Figure 2). This two conditions are applied in order to test the ability to learn the spatial positions of specific locations in complex city environment after one trial navigation using GPS-like map of the environment. Pointing towards the start and target locations are required at the end of each learning/recall trial.

Figure 2. *Illustration of the Eye-tracking experiment from the first-person view: (left) the route following condition (route marked by a blue line); (right) the wayfinding condition (simple map).*

In addition, we will analyse the effect of long-term AR glasses wearing on the eye movements. The following characteristics of the eye movements are measured: Fixations (eye fixating on a specific location of the screen), Saccadic Eye Movements and Microsaccades (small < 0.25 degrees), involuntary eye movements that typically occur during fixation. Possible changes in eye-movements can be related either to physiological reasons (for details see Eye examination section 2.1.1.) or to cognitive effect of the navigation training using the AR glasses, possibly resulting in increased number of fixations on the map placed in the left corner of the screen. Behavioural performance in spatial navigation Virtual city test will be evaluated in terms of group differences in duration of individual trials and path efficiency (real vs. minimal possible trajectory) contrasted towards the time spent looking at the GPS-like map of the environment during the learning and recall trials.

2.2.4 fMRI experiment. Navigation in the virtual city is subsequently tested using the fMRI paradigm. The map of the environment is no longer presented during this experiment. Participants visit each of the previously learned locations just once in the fMRI task in the following fashion: 1 pair of locations is used as a training for the later fMRI measurement with the remaining 20 pairs of locations. All pairs of locations used in fMRI task differ from the pairs used during the eye-tracking experiment. Each pair of locations is used in one of two conditions, either in A) *wayfinding* trials - experimental condition requiring active navigation and recall of the target position from memory (according to its specific name), without an arrow showing the direction to the target location, and B) *route following* control trials with an arrow showing direction towards the goal location (without naming the goal location in order to prevent the subject from navigating according to his/her own memory), for illustration see Fig. 3. Each trial starts with a teleportation followed by pointing towards the target location (in wayfinding), or near visible location (rote following). The two conditions are alternating (max duration of trial is 60s) in an event-related fMRI paradigm (EPI sequence) and will be contrasted to obtain activation (BOLD contrast) specific for spatial navigation abilities during wayfinding. Behavioural performance in Virtual city test will be evaluated in terms of group differences in the duration of individual trials, path efficiency (real vs. minimal possible trajectory) and distance from the target location (in case the target was not reached in the 60s time limit). Please notice the reasons for the following changes in contrast to the eye-tracking paradigm: 1) the route following trials serve here only as a simple control condition for fMRI contrast (not as a comparison for previous Eye-tracking measures); 2) the map of the environment was removed in order to test the ability of the subjects to effectively navigate after learning with the GPS-like device.

Above described fMRI navigation paradigm (EPI sequence) is performed on the 3T Siemens Prisma magnetic resonance imaging (MRI) scanner placed in NIMH facility. Our neuroimaging protocol includes also anatomical scan sequence (T1 MP-RAGE, 1mm slice thickness), diffusion weighted imaging (DWI), and 10 minutes resting state functional magnetic resonance (resting fMRI). In the structural and functional analyses, we will primarily focus on hippocampus, dorsolateral prefrontal cortex and basal ganglia as these are structures usually reported to be involved in spatial cognition. Data analysis methods will include e.g. functional and effective connectivity, Tract-Based Spatial Statistics (tractography) and Voxel Based Morphometry (VBM).

Figure 3. *Illustration of the fMRI experiment: (left) route following condition (with direction arrow); (middle) the wayfinding condition; (right) Schematic map of the virtual city (top view).*

2.2.5 Map recognition experiment. Colour printed schematic map of the environment (see Figure 3, image on the right) is presented to all participants after the fMRI experiment. Participants are asked to recall the locations visited during the fMRI/eye-tracking experiments and note them into the schematic map.

2.2.6 In the field AR glasses usage navigation. Before and after the minimum of 10 weeks usage period of Vuzix M100 participants are asked to navigate themselves in the real environment in order to get from the starting position to the end position using the paper map and then using the Vuzix M100 smart glasses. During the 10 weeks period they are asked to use the navigation app of the device in a passive mode that provides them with a continuous information about their location on the map.

3. CONCLUSIONS

The study addresses underlying mechanism of interfacing with the HCE device and possible effects of such human-machine interfacing, in both the corporeal and cognitive enhancement. In the light of new technologies emerging in our every-day life it is crucial to study possible changes occurring during human-device coupling. This can be achieved using above mentioned methods ranging from questionnaires (addressing mainly the acceptance of the HCE device), through behavioural and physiological measures. In addition, possible health issues (risk factors) related to the usage of HCE technology of Smart glasses (such as the changes in vision) are studied both in complex examination of vision and in the eye-tracking experiment. The submitted poster will present our preliminary behavioural and imaging data.

Acknowledgements: This research has received funding from the Norwegian Financial Mechanism and the Ministry of Education, Youth and Sports under Project Contract no. MSMT-28477/2014, Project Nr. LO1611 with a financial support from the MEYS under the NPU I program.

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Remediation of cognitive deficit in neuropsychiatric disorders using virtual carousel task and episodic memory task

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ABSTRACT

The impairment of cognitive functioning represents a characteristic manifestation in various neuropsychiatric disorders, such as schizophrenia (SZ). Previous studies demonstrated mild to severe deficit almost in all cognitive domains. Our results obtained in the virtual analogue of the carousel maze also demonstrate impairment of spatial memory and cognitive flexibility in schizophrenia patients. In addition, results of the episodic-like memory task (EMT) also support the hypothesis of episodic memory deficit in schizophrenia. The aim of the presented study is to improve these impaired cognitive functions using remediation methods based on similar methods in a complex virtual environment. The remediation plan will be presented together with preliminary data obtained in a small group of schizophrenia patients.

1. INTRODUCTION

Cognitive deficit is considered to be a characteristic and permanent manifestation accompanying schizophrenia (SZ) and related psychotic disorders, affecting several cognitive domains (Green et al, 2004). The profile of deficits in schizophrenia includes among others also attention, working memory, reasoning and processing speed. Common to these abilities is the role of prefrontal cortex (PFC). The impaired ability to identify context using task-relevant information stored in a working memory, involving PCF hypofunction, was also described in SZ. Similar observations have been done in various task-switching paradigms (Jamadar et al, 2010). Moreover episodic memory deficits dependent on hippocampal (HPC) function are well-established among individuals with SZ (Aleman et al, 1999), often linked to strategic memory failures. The core of complex cognitive deficits observed in schizophrenia could be the impairment of cognitive coordination (neural control of cell population activity in time and context) controlled by hippocampal and prefrontal cortex (Phillips and Silverstein, 2003). This presumption is supported by the fact that frontotemporal dysfunction was demonstrated in schizophrenia (Meyer-Lindenberg et al, 2005). In order to assess and possibly remediate spatial abilities focused on episodic memory and cognitive coordination, we designed a computer-based episodic memory task (adopted from Vlcek et al, 2006) and a virtual task-switching paradigm in dynamic environment (Fajnerova et al, 2015).

2. EXPERIMENT 1 – THE EPISODIC-LIKE MEMORY TEST (EMT)

2.1 Method

2.1.1 Participants. Sixty-five subjects (39 males and 27 females, group SZ) who met ICD-10 criteria for first psychotic episode of schizophrenia spectrum disorder (F20.X (n=4) and F23.1/F23.2 (n=32)). The healthy control subjects (N=100, 50 males and 50 females, group HC) were recruited from the same socio-demographic background via a local advertisement. The average age of both groups was 28 years (SZ: 28.8 ± 7.7; HC: 28.7 ± 9.1), and most of the participants in both groups had education level 4 (university).

2.1.2 Clinical assessment. To confirm the cognitive deficit in our study subjects, all participants (SZ and HC) completed a battery of standard cognitive tests (Trail-Making Test; Spatial Span (WMS-III); Rey-Osterrieth Complex Figure Test; Block Test (WAIS-III); Perceptual Vigilance Task (PEBL), Money-Road Map Test, Key Search Test). In addition, all patients were evaluated using the PANSS and GAF psychiatric scales to address the presence of clinical symptoms.

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2.1.3 The non-verbal working memory form of the Episodic-like Memory Test (EMT). The computerized EMT test (previously published by Vlcek et al, 2006) is based on the concept of testing the memory for information about **'where'** a specific event (episode) took place, **'what'** occurred during this episode, and **'when'** it happened (Clayton and Dickinson, 1998). The test was adjusted in order to test the short-term memory for episodic events, consisting of a presentation and a testing phase (see Figure 1- left). In the presentation phase, the subject was shown a computer screen with several objects (pictures) in predefined places on the right part of the screen and an empty open box on the left. The tested person was instructed to drag the pictures from the predefined places in a given order into the chest, using the computer mouse. The subject was asked to memorize both the order and the position of each picture. After a short delay (of several seconds), in the following testing phase the subject was shown all the pictures dragged during the previous presentation phase to the box placed in one single row at the bottom of the screen in a pseudorandom order (see Fig.1). He/she was then asked to drag the pictures in the same order as they were dragged into the box to their correct position. The test is performed in three successive levels of difficulty: three, five and seven pictures of common objects. We evaluated separately two aspects of the information: errors in the "where" (position of the pictures) and "when" information (order of the pictures).

Figure 1. *EMT test: presentation phase and testing phase (left); The virtual Carousel maze task: Schematic view of the two reference frames - Room (square shape) and Arena frame (circular shape) and arena from the first-person view (right), adjusted according to [Fajnerova et al, 2015]*

2.2 Results

2.2.1 Cognitive assessment. The non-parametric Mann-Whitney U test showed impaired performance almost in all neuropsychological measures focused on learning and long-term memory, working memory, attention, processing speed and mental flexibility, executive functioning and specific spatial abilities (mental perspective taking). The detailed results are not presented (for details see Fajnerova et al, 2015).

2.2.2 EMT results. The repeated measures ANOVA showed significant group effect both in EMT position and order errors ($p < 0.0001$). Similarly, the difficulty level (number of pictures used during the test) had significant effect both in spatial and temporal component ($p < 0.0001$). However, the significant interaction effect (group x difficulty) was found only in the memory for ORDER, but not for POSITION (see Figure 2).

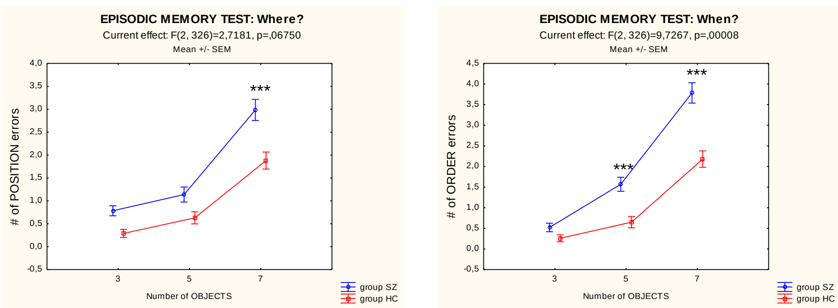

Figure 2. *EMT group results for both POSITION (left) and ORDER (right) errors (*** p < 0.001).*

3. EXPERIMENT 2 – VIRTUAL CAROUSEL MAZE TASK (ACTIVE ALLOCENTRIC PLACE PREFERENCE)

3.1 Method

3.1.1 Participants. A study group of 30 (17 males, age 18-35) first-episode schizophrenia patients (SZ, diagnosed as acute psychotic episode or schizophrenia according to DSM-IV) and a matched control group of healthy controls (HC, n=30) were recruited and matched for age, sex, education level and gaming experience.

Proc. 11th Intl Conf. Disability, Virtual Reality & Associated Technologies
Los Angeles, California, USA, 20–22 Sept. 2016

3.1.2 Clinical assessment. All participants (SZ and HC) completed a battery of standard cognitive tests (for details see section 2.1.2).

3.1.3 Apparatus and software. The game engine Unreal Engine (Epic Games) was used to visualize the virtual scene to the respondents presented in a first-person view on a 24" LCD monitor. The custom-made java software toolkit called “SpaNav” was connected to the game engine to control the experiment and collect data. Subjects controlled their movement in the virtual environment using one joystick of the gamepad device.

3.1.4 Design and Procedure. Prior to the experiment all participants underwent a short pre-training of movement control in complex virtual maze. Consecutively all performed experiment in the virtual Carousel maze task, called also the Active Allocentric Place Preference task (AAPP, Fajnerova et al, 2015). The hidden goal principle was used to test spatial abilities in subjects standing on a rotating arena. The hidden goal positions were connected either 1) to the ARENA frame (rotating together with the subject) or 2) to the ROOM frame moving with respect to the subject/arena (see visible goals illustrated as circular or squared shapes in Fig. 1 on the right). The task was divided to four separate phases: *1) Training* - searching for two goals, one in the arena frame and one in the room frame; *2) Arena frame* - navigation towards two goals rotating with the arena and thus stable in respect to the position of the subject; *3) Room frame* - navigation towards two goals stable in room frame and thus moving in respect to the subject standing on the rotating arena; *4) Frame switching* - alternated search between 4 goals placed either in arena frame or in room frame. Each single trial started with pointing towards the goal and was followed by navigation (20s time limit) towards the goal using 3 visible orientation cues. The performance in the *Rotating arena* was measured using the *pointing error* parameter and the *trial time* parameter (time needed to enter the goal position). Only the data for the trial time parameter are presented in this paper as the most sensitive measure of behavioural impairment in schizophrenia.

3.2 Results

All phases of the virtual Carousel maze task showed decline of spatial performance in SZ: 1.*Training phase* showed impaired learning abilities ($p < 0.01$, Fig. 3A); 2. *Arena frame* showed mild impairment in navigation towards stable goals ($p < 0.01$) less expressed in the second half (Fig. 3B); 3.Room frame showed strongly impaired navigation towards the moving goals connected to the *Room frame* (Fig. 3C) showed strongly profound decline of spatial abilities in SZ ($p < 0.001$); 4. Frame-switching paradigm showed substantial deficit in SZ patients ($p < 0.001$, see Fig. 3D).

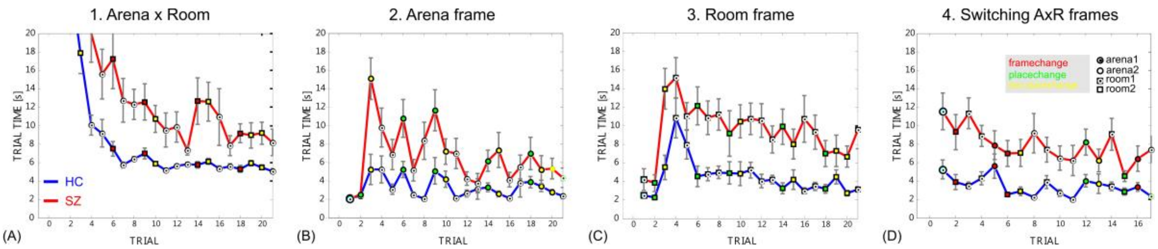

Figure 3. *(A-D) Group performance in four phases of the virtual Carousel maze task expressed using the Trial time parameter. (A) Training phase with simple frame switching (1arena x 1room). (B) Arena frame performance. (C) The Room frame performance. (D) Alternation between 4 previously acquired goals, placed in two reference frames; adopted from [Fajnerova et al, 2015].*

4. VIRTUAL REMEDIATION PROGRAM

Both tasks EMT and Carousel maze have a spatial component. We believe that such spatial tasks have the potential to assess cognitive performance in ecologically valid environments. Our aim is thus to apply similar methods in cognitive remediation program in SZ aimed at complex cognitive abilities:

A. **Episodic memory** – paradigm involving memorizing of objects position and order in complex virtual scenes (see Figure 4). The difficulty level can be increased in the course of the training program 1) by means of the number of objects that should be remembered (starting by 3 and increasing by 1 object after successful trials up to 10 objects), and 2) in the means of complexity of the virtual environment ranging from simple virtual rooms (e.g. offices or houses) to a large-scale environments of a small virtual city.

B. **Spatial memory and cognitive coordination** in a switching paradigm involving switching between spatial reference frames in dynamic environment of the Carousel maze. The training will take place in the following phases: 1) one goal position on a stable arena (without rotation); 2) switching between 2 goals on a stable arena; 3) two goals rotating together with the arena; 4) one goal attached to the room frame (requiring navigation towards the moving object) with no arena orientation cues as distractors; 5) one goal in the room frame with distracting arena cues; 6) two goal positions connected to the room frame; 7) two goals rotating with the arena and two goals connected to the room frame. Difficulty level can be also adjusted using increasing number of distracting orientation cues in the environment and the complexity of the environment outside the arena (ranging from room to complex city environment surrounding the rotating arena).

Figure 4. *Illustration of the Episodic memory (for position and order of several objects) training task in the virtual office environment. The arrow points towards the next object in the sequence that should be picked-up and remembered. On the bottom of the scene is the object inventory showing objects that should be later placed in the correct sequence back on the same locations. Objects in the inventory are randomized in the beginning of the recall phase.*

4. CONCLUSIONS

The presented results show significant deficit of spatial abilities in first episode schizophrenia patients, both in spatial memory and mental flexibility tested in dynamic environment of rotating arena, and episodic memory tested in simple computer task. As individual phases or difficulty levels of these tests demonstrate variable extent of sensitivity towards the cognitive deficit in SZ, we propose this tasks as suitable tools for virtual remediation of impaired visuo-spatial abilities and cognitive coordination in schizophrenia. Based on these results we propose a complex cognitive remediation in two virtual reality tasks enabling us easy manipulation with environmental stimuli that could help us to prevent boredom and increase the motivation of trained schizophrenia patients, and good control over the increasing difficulty level necessary for effective training.

Acknowledgements: This study was supported by the projects IGA MH CR grant NT13386, "National Institute of Mental Health (NIMH-CZ)" ED2.1.00/03.0078 and project Nr. LO1611 with a financial support from the MEYS under the NPU I program.

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Motion sickness related aspects of inclusion of color deficient observers in virtual reality

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ABSTRACT

Color blindness is one of the most common forms of disability. Virtual reality (VR) development has increased recently, and it is important not to exclude people with impairments or other limitations. Visually induced motion sickness (VIMS) can be worse due to color versus black, white and gray environments. Can non-color factors in dynamic environments be excluded by performing color deficiency impacted tasks and comparing them to the equivalent static and dynamic tasks performed by a color-sighted person? Would a color-based experiment causing VIMS produce different results for a color deficient observer (CDO)? This paper advocates a novel approach to color blindness and motion sickness in VR based on psychophysical experiments. The aim is to find solutions and develop recommendations that will improve accessibility of VR for the colorblind.

1. INTRODUCTION

Color blindness is one of the most common and widespread forms of disability in humans. The total frequency of color vision defects reaches up to 8% in males (Deeb, 2005) and at least 0.5% in females (Sharpe et al, 1999). The term *color blindness* in itself is covering several types of color deficient observers (CDOs), predominantly those affected by the so-called *red-green blindness*, also known as *anomalous trichromats*, along with some *dichromats* and rare *monochromats*. It has been estimated that ~2% or almost 6.5 million people in all age categories of the 2002 U.S. census have a non-severe visual impairment that affects gameplay (Yuan et al, 2011). This is not surprising, given that the most common inherited color defects are the aforementioned red-green ones (Pease, 2006), and more than 75% of red-green colorblind individuals experience some difficulties with daily tasks (Steward and Cole, 1989).

Some game developers, such as Rockstar North (Grand Theft Auto IV) and Epic Games (Unreal 4) have incorporated colorblind accessibility solutions into their products (Ellis et al, n.d.). However, the renewed interest in virtual reality (VR) exposes an area where accessibility remains relatively unexplored. In particular, it becomes important to find out if motion sickness in VR affects CDOs differently than it does viewers with normal trichromatic vision, given that color-sensitive cones concentrate heavily near the middle of the field of view in the retina. Two prior studies (Bonato et al, 2004; So and Yuen, 2007) disagreed as to whether color plays a role in the phenomenon of motion sickness in VR, so this more general issue has to be addressed as well.

Bonato et al (2004) reported that motion sickness onset was faster and more severe when observers were shown chromatic stripes, as opposed to showing black, white, and gray stripes only. The performance of a CDO is not purely a function of the color, but also influenced by other factors that are not yet fully understood. Can non-color factors in dynamic environments be excluded by performing color deficiency impacted tasks and comparing them to the equivalent static and dynamic tasks performed by a color-sighted person? A related question is: would a color-based experiment causing visually induced motion sickness (VIMS) give different results for a CDO?

2. MOTIVATION AND BACKGROUND

Surprisingly many CDOs remain unaware of their color defiency until tested, usually with color differentiation and so-called *color confusion lines*, which are simplified descriptors in a static environment. This suggests that the CDOs use some forms of visual input other than color to help or augment their color distinction and differentiation. Color deficiency and color confusion lines are very good descriptors in an aperture mode view of color, meaning a scenario where two pure color sensations have to be matched. Many static tests exist, among them the well-known Farnsworth-Munsell 100 Hue Color Vision Test (Farnsworth, 1943), the RGB Anomaloscope (Nagel, 1907), or the Ishihara test (Ishihara, 1917). The latter one is the most widely used test for color deficiency, unless one counts simple tests administered to prospective drivers. All of these static tests are repeatable and their results are stable. This reproducibility seemingly presents a stark contradiction to the relatively low level of awareness among the CDOs.

The explanation proposed by Eschbach et al (2014) is that, in realistic viewing situations, CDOs compensate for their disability by utilizing other available cues. In that work, it was shown that a simple modification of the Ishihara plates led to a strong change in the ability of CDOs to identify the colors. In their examples, Eschbach et al did not modify the color per se, but merely changed the spatial arrangement and edge formation of the colors. This modification did not allow a higher cognitive level to enter the experiment. No higher level objects or knowledge could be used, since the actual plate still consisted of dots of given colors at quasi-random position. The result strongly suggests that there are additional sources of information that a CDO makes use of and that these sources are not well known or understood. Thus, complex static environments already challenge several aspects of the extension of standard color deficiency models, such as the popular one based on replacement colormaps and developed for the relatively narrow purpose of evaluation of display legibility (Viénot et al, 1999). Complex dynamic environments such as VR are therefore likely to show even stronger effects leading us to better understanding of the color and VIMS phenomena and toward improved utilization of the VR technology.

3. OPTOKINETIC DRUM AND SPHERE SIMULATION

Simulator sickness (nausea, headache, disorientation etc.) experienced by the observer poses a serious challenge to VR developers. Some people are significantly more susceptible to simulator sickness than others, the factors in play including age, ethnicity, gender, and experience with the simulator (Kolasinski, 1995). The most widely accepted explanation of simulator sickness is the theory of cue conflict (McCauley and Sharkey, 1992). In line with this theory, simulator sickness can be classified as VIMS. Two tentative hypotheses are: 1) The reaction of CDOs to the signal is muted, and thus motion sickness sets in at a later stage; and 2) Additional information that seems to be used by CDOs will be amplified and thus create a stronger motion sickness.

3.1 The Simulator

Bonato et al. (2004) studied visually induced motion sickness using an *optokinetic drum*, a rotating instrument in which a test subject is seated facing the interior wall of a cylinder covered with patterns. A similar instrument of a different geometrical shape is known as an *optokinetic sphere*. As Bonato et al (2004) did not investigate the color blindness aspect of the problem, two of the co-authors of this paper contributed to the development of a VR simulator designed to study the effects of color and color blindness on motion sickness using head-mounted displays (Gusev et al, 2016). The VR simulator included both an optokinetic drum and sphere, using a popular HMD (Samsung Gear VR). Stripes and checkerboard patterns are used. Gusev et al (2016) describe the details of the design, including the method of selecting colors so that when they are viewed through a color blindness simulator, the colors become indistinguishable from each other. In addition to the normal color vision mode, eight types of color blindness are simulated, based on the color mapping approach of Viénot et al (1999).

3.2 The Psychophysical Experiment

The psychophysical experiment that is currently underway at the Envision Center of Purdue University is designed as follows. The goal of the psychophysical experiment is to collect the subjective visually induced motion sickness detection and assessment data for measurement of the effect of color and color blindness on VIMS in VR. Before the experiment, the subject is asked to do a standard Snellen visual acuity test and an

Ishihara color blindness test. Both colorblind individuals and those with normal color vision are included in our observer pool. People who do not have normal visual acuity (corrected to be 20/20 Snellen acuity) or are not able to understand the instructions are excluded from subject pool. The subject is also asked to fill out a preliminary questionnaire aimed at assessment of the subject's susceptibility to motion/simulation sickness. The experiment is conducted in a controlled lab. Oculus Rift DK2 and Samsung Gear VR units are used. During the experiment, the subject is asked to perform tasks in a VR simulation of an optokinetic drum (or sphere). As the drum rotates, the subjects observe a moving visual field while their bodies remain stationary. With the subjects that have normal color vision, up to 9 simulation modes can be used. Stripes and the checkerboard pattern are tested. The VR optokinetic drum controls allow the observer to speed up rotation, slow it down, or stop entirely at any time. The observer responses are recorded in the simulator sickness questionnaire (Kennedy et al, 1993).

4. THE PATH FORWARD

Even as the current experiment is progressing, we feel the need to deviate from the approach of Viénot et al (1999) as the sizes of color stimuli in VR may far exceed those involved in evaluation of display legibility. Indeed, one of the more common mistakes made by people with normal color vision when they select paint color for painting walls of a room is to look at the relatively small color samples available at a store, possibly even hold the sample cards against a wall, and select a color that's too bright, chromatic, or saturated. Once the whole room or a sufficiently large area of its walls is painted in that color, the bold color comes across as too strong/harsh. This may seem counterintuitive, given that color perception changes across the visual field so that it is best in the fovea and declines in the periphery. Moreover, sensitivity to red-green color variations declines more steeply toward the periphery than sensitivity to luminance or blue-yellow colors (Hansen et al, 2009).

However, one should bear in mind that human vision system has an *averaging (integration) property* that acts as one of the noise-reducing mechanisms that aim to reconstruct a more faithful representation of the stimuli (Lombrozo et al, 2005). Sometimes, these mechanisms fail and contribute to such optical illusions as Mach bands (Ratliff, 1965). We suspect that these mechanisms are at least partly responsible for the color selection mistake discussed above, as they reduce the signal-to-noise ratio (SNR) for the large stimuli, even despite the reduced color sensitivity in the periphery. Some CDOs may be able to see the color once the stimulus is large enough, despite the inability to pass the Ishihara color blindness test, with its small colored blobs. What this also means is that the simple static color mapping should fail to correctly simulate color blindness for large color stimuli in VR. Hence one natural follow-up to the ongoing experiment is to either vary the widths of the stripes and sizes of the checkerboard squares, or allow the observer to get closer to the moving wall in the VR simulator.

5. CONCLUSIONS AND FUTURE WORK

Examining CDOs in complex dynamic settings is important for three separate, but equally fundamental reasons: 1) In contrast to the color-sighted viewers, CDO performance is a function of the static vs. dynamic environment. In a virtual environment, certain natural cues or information channels may be omitted or misrepresented. This might have had minimal effect on a color-sighted person, since other signals were stronger, but muting the other signals then exposed the deficiency of the virtual environment. In a sense, the virtual environment may have created a new barrier for CDOs. However, without having all cues identified and classified, it is impossible for the creator of such environments to avoid these pitfalls; 2) Identifying cues that differentiate the CDO, one can postulate that at least a small effect of these cues is also present for the color-sighted observer. In a virtual environment, we then have the conscious and controlled option if we want to emphasize or de-emphasize such cues in order to enhance or diminish effects for the color-sighted observer; and 3) If we make the determination that colorblind people can complete some tasks in VR that normal viewers cannot due to VIMS, it will represent a major step forward in our understanding of the complex interrelationship among color, color blindness, and motion sickness. Indeed, some colors, such as red, are commonly perceived as more "aggressive" than others, and certain "psychedelic" color combinations reportedly help cause motion sickness and nausea in video games (Far Cry Primal Forum, 2015). We expect this effect to be even more pronounced in VR.

With these three reasons in mind, we plan to expand the psychophysical experiment to cover a second type of VR systems, in addition to the HMDs, — the CAVE projection-based immersive environment with walls. The properties of these two types of VR with respect to task completion were reported to be different by Kim et al. (2012), and we want our results to be as general as possible. We also intend to use realistic virtual environments, in addition to those specifically designed to cause VIMS. We believe that the results of this future work will have positive impact on the design process of modern VR games and simulations so as to broaden participation of people with such disabilities as motion sickness susceptibility and color blindness.

Acknowledgements: The authors thank Dr Brad Duerstock, Dr Cary Supalo, Mr George Takahashi, Dr Rustin Webster, and Dr David Whittinghill of Purdue University for their help and advice.

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Labyrinth game with Kinect control

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ABSTRACT

Stroke changes not only the patients' lives, but also those of their families. The improvement of the active movement of the upper limbs is of great importance after stroke, which helps regain self-sufficiency and the recovery of fine movements. One of the key elements is the development of the active movements of the arm and fingers. The aim of the Flash-based labyrinth game of the article is to develop these motor skills, and that the patients may become self-sufficient in their home environment, or capable of working by the end of the rehabilitation. The Labyrinth Game is focusing on the movement of arms and elbows, out of the 17 exercises of Wolf Motor Function Test's (WMFT) upper limb rehabilitation tasks. The game uses simple forms and colours, and contains understandable and useable menus for more efficient usability.

1. INTRODUCTION

The aim was to develop and implement a labyrinth game so that patients will be able to continue their rehabilitation in their home environment to become self-sufficient, moreover get fit for work. Stroke can create occlusion of veins, or necrosis due to haemorrhage. The most common signs and symptoms are the lack of strength, hemiplegia, and the paralysis of upper limbs. There might be a disorder in movement co-ordination, which can result in vestibular disorder and inaptness of limbs. In case of damage of the dominant cerebral hemisphere, speech disorders, or in extreme conditions, even aphasia may appear. During the precession of the symptoms the patients require acute medical attendance. Rehabilitation might get started when the process stabilises and the unimpaired areas start to work again (Vogiatzaki, 2016).

The main element of the rehabilitation program is physiotherapy, which might be carried out actively, passively, individually or within a group.

2. STANDARD REHABILITATION METHODS

Researches claim that stroke patients taking rehabilitation at a home environment, with a positive atmosphere, are more likely to regain their individual life-style. Of course, rehabilitation and recovery highly depend on which part, and in what extent is the brain damaged. The aim of the rehabilitation for the patient is to re-learn the previously known skills and to recover self-dependence as much as they are capable of.

During active rehabilitation the patient completes the tasks independently with the help of a physiotherapist; having reached a certain level, they can continue rehabilitation at home to maintain their knowledge and up the level of rehabilitation. Recently, several methods and therapies exist and are available with the application of which a considerable improvement can be gained in post-stroke rehabilitation. With their appropriate usage, the recovery time might be shortened and the patients may return to their former life-style much earlier.

2.1 Support recovery with physiotherapy

One of the methods to speed up recovery is the usage of adequate physiotherapy. The slow and progressive movements should be carried out continuously, till the toughness of the limbs disappear.

2.2 Music therapy

Music, as a whole of characteristic vibrations, can achieve peculiar spiritual and physiological effects. As a therapy, the active and passive varieties of music are used. During active music therapy the patients are singing or using musical instruments for the development of partial learning skills as concentration, memory or creativity. With the application of passive music therapy (receptive therapy) different areas can be improved with chosen music (American Music Therapy Association).

2.3 Pető method

Besides development of children, András Pető is dealing with the rehabilitation of function disorders in adulthood. As the plasticity of brain remains after childhood and adolescence, there is an opportunity in any age group to set up new cerebral connections. During the program the patients can learn movement coordination, correct posture, walking and fine motoric movements. If required, attention, concentration and communication might also be developed (Bandolier).

2.4 Rehabilitation with computer games

Stroke is physically, emotionally and economically demanding; the medical institutes do not have the opportunity to cater the patients during the whole rehabilitation process. 6 months after stroke, 80-90% of stroke patients still have problems with arm movements; however, the lost functions can be regained with the appropriate devices. There is a great need for serious games, with the help of which the patients can exercise in their home environments. These games help the recovery and development of patients without the continuous supervision of the therapist in a comfortable environment. With the application of rehabilitation methods the movement of arms and hands are developed independently, while with serious games both of them might be improved at the same time. Some of the games improve the coordination, accuracy and speed of the arms and hands (e.g. Plasma Pong), other simulations develop the accuracy of finger movements and grabbing (e.g. Virtual Piano). The application of serious games shows decisive improvement; the impaired limbs became more stable. Thus, it has been proved that the usage of rehabilitation games, with 2-3 hours of practice at home environment might improve the conditions of patients (Burke, 2009).

2.5 Rehabilitation results with active games

Rehabilitation researches with video games show that during their recovery the patients retrained the lost strength and motoric functions of their limbs within a shorter time thanks to the games.

In a research – aimed for stroke rehabilitation – the results showed that repetitive exercises help the development of arm and hand functions of stroke patients. In the test the users had to touch virtual objects in a virtual environment. Patients taking part in the testing were completing tasks in the virtual environment with a help of a robotic arm. After the 2 weeks long testing period the results showed that the patients could move their arms much quicker thanks to the repetitive movements, than before the therapy. Despite using robotic arms for accomplishing the tasks, the results showed that the number of connections between different brain areas had increased. The results are enticing; the robotic arm assisted physiotherapy and virtual reality might help in the recovery of stroke patients (Laino, 2010).

2.6 Limitations of home rehabilitation

Despite the help of physiotherapists and families, due to the fact that the recovery is ill-progressing, during the rehabilitation, patients suffer from changing moods, a negative attitude toward the treatments, or passivity (Legg, 2004).

It needs to be taken into account, whether the patient can fully complete the tasks mentally and physically. If the task is too difficult or too much for the patient he/she might get exhausted. If they cannot complete the tasks they might get disappointed, and because of the negative experiences they might lose the interest in the games. This way the rehabilitation will not progress well and will not have good results.

3. LABYRINTH GAME WITH KINECT CONTROL

In the article the design and implementation of a computer-based rehabilitation game will be presented. The game is set up of 2 fields: in the first one the patient has to collect a number of objects from different places on the field based on the given level of difficulty; in the second field they have to create a meaningful word of the given letters. At the realization of the game it had to be taken into account that the program is dedicated for the rehabilitation of stroke patients. In this case an easily applicable game with rich visual and audio background had to be developed that the patient can easily use and enjoy every day to help their recovery. Another important aspect of the program was to cover the tasks of WMFT, which do not require special devices or weights for the completion of the exercises.

Another important aspect was to use peripheries that are available for everyone (such peripheries were searched for, which are available for every user, or can be purchased easily for a low price). The game needs to inspire the patient for moving, this way it needs to be funny, but challenging at the same time. An easily applicable and understandable surface has to be created, so that it can be used by everyone despite the age groups.

3.1 First steps – requiremets specification

The task was to design and implement a Flash based labyrinth, where the player first has to gather the treasures on the field of the labyrinth, and after it – in the next field – they have to create a meaningful word out of the letters, the number of which equals with the number of treasures.

In the development of the program the arm, elbow and shoulder movements of the WMFT test have been taken into consideration. The aim of the game was to cover as much exercises of the 17 movements as it is possible. If it is possible, the program – besides using a mouse – has to be controlled by a sensor device as well. During the research no solutions were found for the problem of connecting PHP based webpages and control them with Kinect sensor, this way the idea had to be rejected. A programming language needed to be found that supports the usage of several sensors.

3.2 Choosing peripheries

As the program was designed for the rehabilitation of stroke patients, such devices had to be chosen that are available in most of the households, or can be easily obtained. During the examination process several devices were found which can be connected with a computer and are supporting rehabilitation.

As a first periphery Mouse had been chosen. It is cheap and available in nearly every household. After connecting it to the computer it is adjustable, so even right- or left-handed people can use it. Although the Mouse can only be controlled while sitting on a horizontal surface, the arms, hands and fingers of the patients are still moving, this way the exercises cover several tasks of the WMFT movements. It is multi-platformed so it is supported by all of the basic operating systems.

As a second device, Music Glove has to be mentioned. This device is appropriate for the therapy of stroke patients, or patients of brain or muscle damage (Caswell, 2015). During the use the patient has to move his/her fingers for music, as in the case of Guitar Hero game. With this game fine movements of hands and fingers can be practiced and also helps the recovery of cerebral neurons. The patients using the device for 2 weeks have reported a decisive improvement. Unfortunately it is not available in Hungary, but it can be easily purchased from online webshops, however, because of its price (which is around $1000) the device is not suitable for home rehabilitation.

Webcameras are relatively common because of their low prices; tey can be used from great distances. Unfortunately, they cannot be used for rehabilitation processes, as they were not designed for tracking movements, thus they cannot accurately locate the limbs. For this problem Kinect sensor is the solution. Microsoft has created Kinect sensor for Xbox games; in the device sensors of microphones and cameras can be found. It has been created for home use. It is a medium-price device. With the suitable drivers it can be used by any computers. The game was finally developed to be controlled with the two most suitable peripheries, the Kinect sensot and the Mouse. For the development a previous version of Kinect, Kinect v1 was used with a 1.8 developer toolkit.

3.3 Labyrinth game

After chosing from 3 different levels of difficulty – beginner, intermediate and advanced – the player can choose from 6-12 previously edited fields. The program creates the field size suitable for the level of difficulty, places the walls on the field and the objects that have to be collected. The player has to practice the exercises of WMFT movements, which do not require special devices or weights. The sideward, vertical and diagonal movements of the arms can be practiced as the player has to pass by the vertically and horizontally placed walls on the field. The navigation between the objects to be collected can be completed by the vertical and horizontal movements of the arms.

3.4 Labyrinth game level editor

The player choses one of the 3 levels – beginner, intermediate, advanced – and has to place, or delete walls on the given field. After level editing he/she can start to play on the field he/she has just designed. The walls can be placed or deleted by buttons. When using the mouse, the player can develop fine movements of the hands and fingers, while by using Kinect shoulder and arm movements can be practiced.

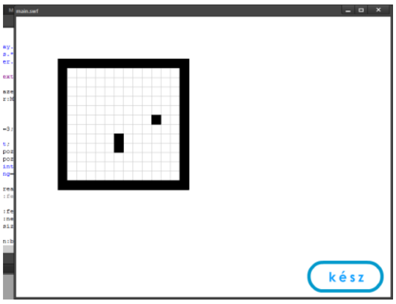

Figure 1. *Level editor's graphical user interface.*

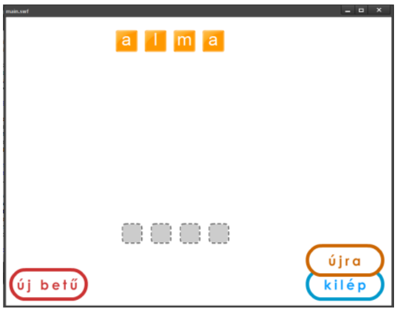

Figure 2. *Word-completition game's user interface.*

3.5 Word game

The user can start the given number of letters at the top of the screen one-by-one as they press the button. The slider at the bottom of the screen can be moved horizontally. The player has to catch the falling letters with the slider. If the player cannot catch the letter, it will not disappear, but will automatically start to fall from the top of the screen, till it is not stored between the caught letters (as the letter touches one of the empty fields of the slider). If the player catches the letter with the wrong field he/she can restart the game and all of the letters will appear shuffled on the top of the screen. The player can start the letters by buttons. To control the slider: in case of using a mouse the player has to move the mouse sidewards, in case of Kinect the arm should be moved sidewards to catch the falling letters.

4. CONCLUSIONS

During the research period preceeding the development, several new results, methods and devices had been found, which have not been used in rehabilitation. During the research period the authors tried to lelarn as much about the illness, the course of the disease, the damages that remain after the disease, the rehabilitation processes and their advantages and disadvantages, as it is possible.

By using the national and international literature during the development the aim was to find out most of the information about the methods and try to use them in the game. On of the criteria in the design of the game was to apply the methods collectively. The basis for the development were the specific movements of Wolf Motor Function Test. Although many types of the WMFT test have been analysed, some of its versions have more tasks, some of them less. After comparison, the WMFT test containing 17 tasks had been chosen.

The complete program was tested by healthy subjects and stroke patients in their home environment. The test were completed by subjects from the age of 7 to 60.The feedback was positive, the subjects found the game manageable and enjoyable. Since the program was designed for rehabilitation purpose, there is a great need to test the game with stroke patients in clinical environment. If there is a need for any kind of modifications, these need to be implemented in the program, thus supporting the home rehabilitation of patients.

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Gaming for health: an updated systematic review and meta-analysis of the physical, cognitive and psychosocial effects of active computer gaming in older adults

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ABSTRACT

Active computer gaming (ACG) is method of enabling physical activity in older adults. This review aimed to determine the effect of ACG on health outcomes in older adults. Four electronic databases were searched to identify 24 eligible randomised controlled studies: 1049 participants; 72.2% female; mean age 78±5 years. Data were pooled for six outcomes, with small to moderate effects observed in favour of ACG for functional mobility and balance outcomes. A large effect was observed in favour of ACG for cognitive function. This review presents evidence that ACG is effective in improving physical and cognitive function in older adults.

1. INTRODUCTION

The fastest growing portion of the population is older adults. Physical activity in older adults is associated with higher levels of physical function and independence, as well as reduced cognitive decline and falls prevention. The American College of Sports Medicine (Nelson et al. 2007) recommend at least 150 minutes of moderate exercise per week, or 30minutes on most days, while a systematic review by Sherrington et al. (2011) recommends interventions of at least 120 minutes per week for falls prevention. Many older adults do not meet these recommendations, reporting various barriers including poor health, lack of social support, and fear.

The use of active computer gaming (ACG) is becoming a recognised method of enabling physical activity in older adults. ACG interventions have been used in trials to investigate their safety, feasibility and effectiveness. Studies have indicated that ACG may contribute to slowing the deterioration of health and function associated with ageing, with favourable results in outcomes such as balance, confidence, functional mobility, and quality of life. The current review updates a previous review of the literature for ACG (Bleakley et al. 2015). This review showed preliminary evidence to support ACG as a safe and effective intervention for promoting physical activity in older adults which may have physical and cognitive benefits; however, it was not possible to pool data for health outcomes due to heterogeneity and insufficient data available.

2. AIMS AND OBJECTIVES

To update and extend a systematic review of the evidence for the physical, psychosocial and cognitive effects of ACG in older adults, and to explore ACG design and intervention delivery. The objectives are:

1. Determine the effect of ACG on physical health outcomes, particularly those related to balance and mobility
2. Determine the effect of ACG on cognitive function and psychosocial outcomes
3. Explore adherence with, and delivery of interventions (ie. dose, setting, supervision)

3. METHODS

3.1 Criteria for selecting studies for this review

A protocol was developed a priori and registered on Prospero (CRD42015017227). This review included randomised or quasi-randomised controlled trials (RCTs) of interventions that used ACG as all or part of the delivery, aimed at improving physical and cognitive function in older adults (>65 years), and published in English. ACG was defined as a digital game that requires players to interact with objects within a virtual context using some part of their body as, or to manipulate, a controller, and requiring some physical exertion. Primary outcomes of interest were related to physical and cognitive function. Secondary outcomes of interest included psychosocial outcomes, such as fear of falling and health-related quality of life.

3.2 Search methods for identification and selection of studies

Four electronic databases (MEDLINE, EMBASE, Cochrane Register of Controlled Trials, and PsycInfo) were searched on 1st February 2015 to identify trials published since the previous systematic review (Week 2 July 2011) using predefined search strategies including a range of subject headings and key words, based on those used in the systematic review being updated. One review author (SH) screened all titles and abstracts, and then retrieved full text reports for the papers that met the inclusion criteria for full eligibility screening, using standardised criteria. Queries were resolved by discussion with a second reviewer (SMcD). A record was kept of all excluded trials along with the reason for their exclusion. Additionally, full texts of RCTs included in the previous systematic review were screened for eligibility for inclusion in the current review.

3.3 Data extraction and management

Data was extracted independently by two authors (100%SH, 50%AM, 50%PD) using a customised form, piloted prior to use. Two authors (SH, KP) independently assessed the included studies for risk of bias using the Cochrane risk of bias tool, grading on each criterion as having low, high, or unclear risk of bias. The kappa statistic was calculated individually for each criterion then averaged to formally assess the level of agreement of the two authors in assessing risk of bias.

3.4 Strategy for Synthesis

Outcomes of interest were analysed as continuous data, and standardised mean differences (SMDs) and 95% confidence intervals (CI) were calculated to pool outcomes. Meta-analyses were carried out using RevMan v.5.3 to compare physical, cognitive and psychosocial outcomes between ACG intervention and control groups. In the case of low heterogeneity (I^2 <50%), studies were pooled using a fixed effects model. Where substantial heterogeneity was identified (I^2 >50%), the random effects model was used to pool results. Effect sizes were summarised as follows: SMD <0.40 = small; 0.40 to 0.70 = moderate; >0.70 = large (Cohen 1988). Sub-group analyses were performed according to: control group, inactive or active; and, studies delivering an intervention dose above or below the recommendation of 120minutes/week, to assess the impact of intervention dose on outcome. Sensitivity analyses were carried out to assess the impact of excluding trials with higher risk of bias in the meta-analysis.

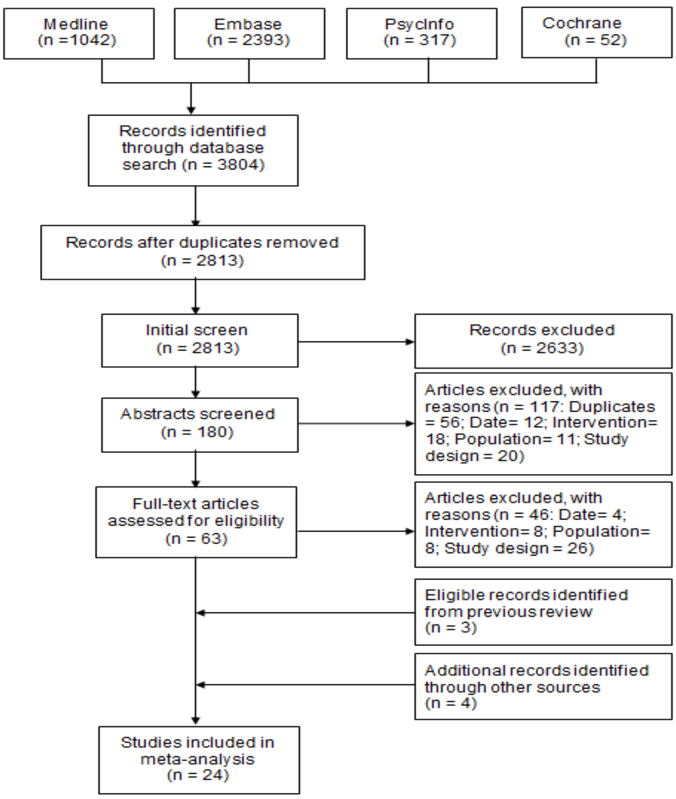

Figure 1. *PRISMA Flowchart.*

Proc. 11th Intl Conf. Disability, Virtual Reality & Associated Technologies
Los Angeles, California, USA, 20–22 Sept. 2016
©2016 ICDVRAT; ISBN 978-0-7049-1547-3

4. RESULTS

4.1 Description of studies

The search strategies identified 3804 references (Figure 1); of these, 63 full text reports were retrieved and screened for eligibility. 24 studies (22 RCTs and 2 quasi-RCTs) have been included in this review, with 1049 participants. The mean sample size was 44 participants. 72.2% of participants were female. The mean age of included participants was 78±5 years. The majority of studies included healthy older adults (n=13). Eight studies recruited participants at high risk of falls. ACG interventions included Nintendo Wii Fit (n=15), Xbox Kinect (n=1), dance mat video game (n=2), and bespoke ACG (n=6). The majority of studies investigated the effect of ACG on physical function (n= 23). Cognitive outcomes were investigated as primary outcomes in two studies, and as secondary outcomes of interest in three studies. Psychosocial outcomes were investigated in terms of quality of life, mental health, and social participation. Details related to intervention delivery are summarised in Table 1. Mean adherence rate reported for the ACG group in n=11 studies was 78.1%. Mean adherence for the control group was 78.2% (n=7 studies).

Table 1. *Table summarising intervention delivery.*

Study ID	*Intervention*	*Supervision*	*Setting*	*Dose (minutes/ week)*	*Adverse events intervention group*	*Adverse events control group*	*Adherence intervention group*	*Adherence control group*
Anderson-Hanley 2012	Cybercycle	NR	Living facility	225	7 (4 study-related)	6 (4 study-related)	NR	NR
Bateni 2012	Wii	SV	Clinic/ research	90	NR	NR	NR	NR
Bieryla 2013	Wii	SV	NR	90	NR	NR	67.5%	n/a
Chao 2014	Wii + behavioural	SV	Living facility	60	0	0	NR	NR
Daniel 2012	Wii	SV	Clinic/ research	135	NR	NR	86%	86%
Duque2013	Balance rehabilitation unit	SV	Falls clinic	60	NR	NR	91%	NR
Franco2012	Wii + HEP	SV	Clinic/research	25	NR	NR	79%	84%
Hagedorn 2010	Computer feedback balance	SV	Falls clinic	180	NR	NR	NR	NR
Heiden 2010	Computer feedback balance	SV	Community	180	NR	NR	NR	NR
Hughes 2014	Wii	NR	Community	90	NR	NR	NR	NR
Jorgensen 2013	Wii	SV	NR	70	0	0	63%	n/a
Kahlbaugh 2011	Wii	NR	Living facility	60	NR	NR	NR	NR
Kim 2013	Kinect	No SV	Clinic/ research	180	NR	NR	NR	NR
Laver 2012	Wii	SV	Living facility	125	13 (10 study-related)	10 (9 study-related)	90%	91%
Lee 2014	Wii	NR	NR	135	NR	NR	NR	NR
Maillot 2012	Wii	SV	NR	120	NR	NR	91%	n/a
Padala 2012	Wii	SV	Living facility	150	1 (0 study-related)	1 (0 study-related)	56%	66%
Pichierri 2012	Dance mat	NR	Clinic/ research	120	NR	NR	70%	60%
Pluchino 2012	Wii	NR	Clinic/ research	120	NR	NR	NR	NR
Rendon 2012	Wii	NR	NR	120	2 (2 study-related)	0	NR	NR
Schoene 2013	Dance mat	No SV	Living facility	45	0	0	86%	n/a
Szturm 2011	Computer feedback balance	SV	Clinic/ research	90	NR	NR	87%	93%
Toulotte 2012	Wii	NR	NR	60	NR	NR	NR	NR
Wolf 2003	Computer feedback balance	SV	NR	45	NR	NR	NR	NR

NR – not reported; SV - supervision; n/a – not applicable

Risk of bias in included studies was assessed using the Cochrane Risk of Bias tool, as of low (n=9), high (n=9), or unclear (n=6) risk of bias (Table 2). There was substantial agreement between the two independent reviewers, with a kappa of 0.67. No conflicts of interest were declared or identified in any of the included studies.

Table 2. *Table summarising risk of bias in included studies.*

Wolf 2003	Toulotte 2012	Szturm 2011	Schoene 2013	Rendon 2012	Pluchino 2012	Pichierri 2012b	Padala 2012	Maillot 2012	Lee 2014	Laver 2012	Kim 2013	Kahlbaugh 2011	Jorgensen 2013	Hughes 2014	Heiden 2010	Hagedorn 2010	Franco 2012	Duque 2013	Daniel 2012	Chao 2014	Bieryla 2013	Bateni 2012	Anderson-Hanley 2012	
+	+	+	+	?	+	+	+	?	?	+	+	−	+	+	?	?	+	?	?	?	−	−	+	Random sequence generation (selection bias)
+	?	+	+	?	+	?	?	?	?	+	?	−	+	?	?	?	?	?	?	?	?	?	?	Allocation concealment (selection bias)
−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	Blinding of participants and personnel (performance bias)
+	?	+	+	?	?	−	−	?	−	+	+	?	+	+	?	?	−	+	−	−	−	+	+	Blinding of outcome assessment (detection bias)
?	+	−	−	+	−	−	+	−	?	+	−	−	+	+	+	−	−	?	−	−	−	−	+	Incomplete outcome data (attrition bias)
+	+	+	+	+	+	+	+	+	+	+	+	−	+	+	+	+	+	?	?	+	+	?	+	Selective reporting (reporting bias)
?	?	?	?	+	?	?	−	?	−	+	+	?	+	+	+	+	−	?	−	+	?	+	+	Other bias

4.2 Effects of interventions

Main results are presented taking into account a sensitivity analysis removing the studies assessed as having a high risk of bias. Twelve studies (n=326 participants) evaluated the effect of ACG on balance and found a moderate significant effect in favour of ACG [SMD 0.52, 95% CI 0.14, 0.91]. Seven studies (n= 234 participants) evaluated the effect of ACG on functional mobility and found a small effect in favour of ACG [SMD -0.31, 95% CI -0.57, -0.05]. A non-significant effect was observed for functional exercise capacity [SMD -0.34, 95% CI -0.79, 0.10]. For cognitive function, data were pooled for a tracking task (4 studies, n=160). A large effect was observed in favour of ACG [SMD -0.82, 95% CI -1.15, -0.50]. Eleven studies (n=470) evaluating the effect of ACG on fear of falling were pooled, with no significant effect [SMD 0.15, 95% CI -0.14, 0.45]. Six studies (n=161) evaluating the effect of ACG on quality of life were pooled, with no significant effect [SMD 0.25, 95% CI -0.07, 0.56].

Sub-group analysis according to intervention dose suggested a dose response for functional exercise capacity, with a moderate significant effect in favour of ACG interventions of >120minutes/week [SMD 0.63, 95% CI 0.19, 1.07; four studies; n=86 participants] compared with a small effect that did not reach significance in interventions of <120 minutes/week. Sub-group analysis did not indicate a potential dose response for any other outcome.

5. DISCUSSION & CONCLUSION

This review identified, graded and synthesised the available literature for ACG in older adults. Overall findings suggest that ACG has a small to moderate effect on physical outcomes, such as balance and functional mobility, and a large effect on cognitive outcomes, in older people. The findings indicate that a higher dose of ACG participation may be associated with a larger positive effect on outcomes related to functional exercise capacity. Most trials included healthy older adults, and were conducted in a clinical setting with supervision. Incidence of AEs was low, their rate and type were comparable to those reported for the control group. Adherence rates, as well as number of and reason for drop-outs, were comparable in intervention and control groups. This supports evidence that ACG is feasible for older people.

This review highlights that ACG is a growing area of research, with the number of eligible randomised controlled studies increasing from 3 to 24 in the four years since the last search. Despite the advances in this research area, trials with small sample size and limited methodological may overestimate the effect of the intervention. Sensitivity analysis, removing studies of lower methodological quality, continued to support the positive effect of ACG; however, the total number of observations remains small, limiting the generalizability of the findings.

Findings of this review suggest that ACG may provide positive physical and cognitive health benefits greater than those observed following traditional exercise or rehabilitation interventions, with a potential dose response for some outcomes. Adherence and adverse events were comparable to those for the control intervention indicating that ACG is feasible for older people.

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Reference list of included studies (n=24): http://bit.ly/29oWZ8l

Pirate adventure autism assessment app: a new tool to aid clinical assessment of children with possible autistic spectrum disorder

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ABSTRACT

Diagnostic assessment of possible Autistic Spectrum Disorder requires multidisciplinary assessment incorporating information from various settings, including psychometric assessment of the child. The Pirate Adventure Autism Assessment App includes a number of these psychometric tests adapted into a pirate adventure storyline. Early experience, presented here, suggests the tool is a useful adjunct to parental history and school questionnaire obtained at initial clinic, in determining the need for the child to proceed to a full, time consuming, expensive, diagnostic assessment.

1. INTRODUCTION

Autistic Spectrum Disorders (ASD) affect at least 1.1 % of the population (CDC, 2014) and maybe even twice this figure with the possibility of under-representation in females. In the absence of a blood test, X-ray, or other scan that can confirm diagnosis, a multidisciplinary process is recommended in the UK requiring information from various sources including home and educational setting, as well as observation and testing for evidence of autistic behaviours and/or patterns of thinking (NICE, 2011). A number of tools have been developed to aid this process including formal structured history tools such as the Autism Diagnostic Interview (ADI-R) and the Diagnostic Interview for Social Communication Disorders (DISCO), and observational tools such as the Autism Diagnostic Observation Schedule (ADOS) and the NEuroPSYchological developmental assessment (NEPSY).

This is a lengthy process, our own study of practice in UK based Child Development Centres suggests this takes around 13 hours of professional time to complete, costing around UK £800 (US $1200) per child (Galliver et al., in submission). This figure does not include costs of ongoing care or further investigation, for example to look for an underlying genetic or chromosomal disorder, nor co-morbid conditions such as ADHD and Developmental Coordination Disorder, even though associated costs may be well in excess of £2.7 billion per year (Knapp et al, 2009). Galliver et al, (in submission) also identified that most teams (10/12) employ a 2 stage process with an initial 60-90 minute screening, or general developmental clinic, often carried out by a paediatrician working alone, at which a decision is made as to whether there is sufficient evidence to justify proceeding to the full multidisciplinary diagnostic assessment (NICE, 2011). With a steady increase in referrals, diagnostic services are coming under increasing pressure to meet the level of need, frequently resulting in waiting times to complete assessment in UK of between 6 months and 2 years (Autism Achieve Alliance, 2014). Therefore any approach that can ease pressure on diagnostic pathways, for example by improving decision making at initial contact, has the potential to improve the quality and speed of the patient journey through the system and even to reduce costs.

2. THE PIRATE APP

2.1 Background

The initial inspiration behind the Pirate Adventure Autism Assessment App (Pirates) concept was a toy pirate ship in the child development clinic. The toy pirates were used in developmental play assessment of the child using a story line based on the Sally Anne Test (Baron-Cohen et al., 1985), a well-established test exploring the child's ability to know what someone else is thinking (Theory of Mind or ToM), thought to still be central to Autistic thinking following the longitudinal SIBS studies (Chawarska et al., 2014). In the original Sally Anne Test, two dolls, Sally and Anne, hide a toy. Anne then goes away, and whilst she is away, Sally hides the toy somewhere else. When Anne returns the child is asked where Anne will look for the toy. A child with typical theory of mind should be able to realise that Anne does not know the toy was moved and therefore will look where she helped Sally to hide the toy originally. We replaced Sally and Anne with two pirates, and the toy with treasure, which appeared to engage the child's interest, the majority of whom are boys, and contributed to the picture of the child. Sometimes unexpected extra information emerged, for example one child objected to the use of a single coin to represent the treasure, demonstrating a pedantic response typical of a child with Asperger's syndrome. Another child demonstrated a higher order of theory of mind, helping to exclude an ASD diagnosis, commenting that whilst the returning pirate would expect the treasure to be where he helped to hide it originally, he might look elsewhere if he thought the other pirate was untrustworthy. Around the same time we discovered Lego Mini-figures, including a range of pirates. These are produced with a wide range of facial expressions, offering the possibility of creating scenarios matching tests of recognition of facial expression (affect recognition), another common area of weakness in children with ASD. With this in mind we conducted a detailed review of the literature underpinning psychometric assessment of children with possible ASD, and around how to design ASD friendly apps.

2.2 Literature Review

A literature search was conducted using the PsycINFO database using the search terms "autism AND (screening OR diagnostic)" to explore available diagnostic and screening tools, yielding 39 relevant studies. A similar search was conducted on current clinical trials databases, and exploring the "app store" for autism diagnostic tools. Current clinical practice and the role of diagnostic tools such as the ADOS and NEPSY were also observed. The review also covered the original literature of psychological theories underpinning current testing including Theory of Mind, False Belief Tests, Affect Recognition and Francesca Happe's "Strange Stories".

Storyboards which have subsequently been built into the tool were constructed incorporating the identified tests, adapted into the context of a pirate adventure story line. This included tests of:

- Affect recognition (e.g. see Golan et al., 2010), including ability to match facial expressions (see Figure 1), identify appropriate situational facial expression (e.g. "how does the captain feel about being made to walk the plank?"), and short-term recall of facial expression.
- First Order Theory of Mind, adapting the "unexpected contents (Smarties tube) task" (Figure 2) and Sally Ann tests.
- Second Order Theory of Mind (Perner and Wimmer, 1985).
- Strange Stories exploring the child's ability to recognise and explain the use of sarcasm and a lie (Happé, 1994).
- Understanding of Idiom, such as "the treasure cost him an arm and a leg" (Barton, 2012).

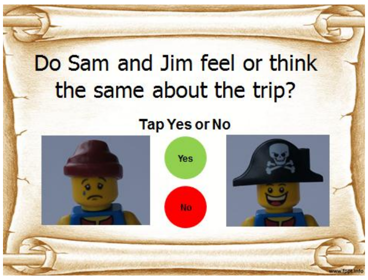

Figure 1. *Example of affect recognition slide*

A further search explored the principles of app design for children on the autistic spectrum. Design features likely to improve engagement included:

- Text should be concise, literal and unambiguous, readable and avoiding capitalising whole sentences.

Proc. 11th Intl Conf. Disability, Virtual Reality & Associated Technologies
Los Angeles, California, USA, 20–22 Sept. 2016
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- Navigation should be clear, e.g. using tap or swipe with clear prompts e.g. buttons or arrows. Buttons should be large and finger friendly.
- Design features should include: uncluttered layout, engaging format and story line, clear feedback (e.g. progress bar), visual images, simple colour palette avoiding black text on white background (visually over stimulating), using easily readable font such as Sans Serif, no time restrictions and no penalising ("errorless learning"), avoiding flashing, fast animations (avoiding sensory overload), abrupt changes, whilst using prompting and reinforcement (Fletcher-Watson, 2015).

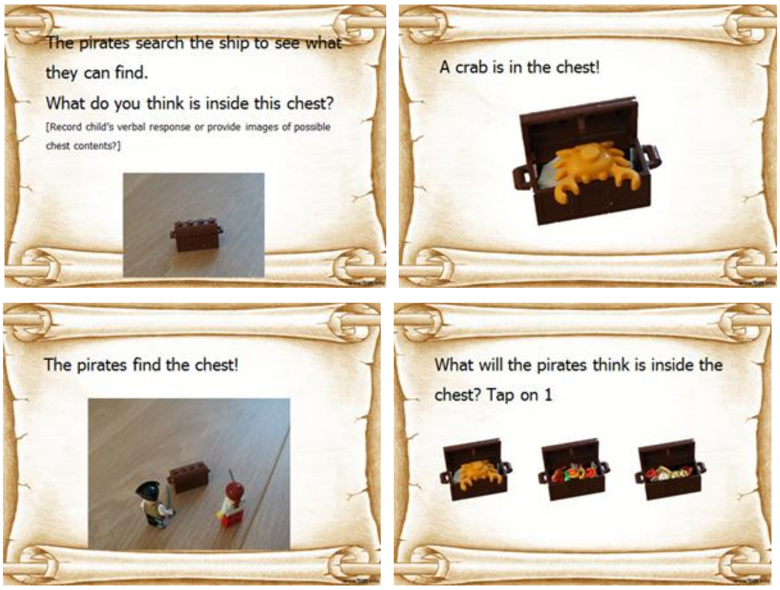

Figure 2. *First Order Theory of Mind Test adapted from Unexpected Contents False Belief Task.*

The resulting scenarios were built into a sequential pirate adventure story line, although most of these can be used as stand-alone tests. The initial PowerPoint and subsequent Apple IOS/Windows versions have incorporated the recommended design features, for example having a Flesh-Reading Ease score of 93.7 (0 unreadable, 100 most readable), use of ellipses, as often used in comics, between slides to maintain suspense, use of a progress bar and touch/tap buttons and Sans Serif.

3. EARLY CLINICAL EXPERIENCE

The app has been piloted by paediatric consultants working in 3 local Child Development Centres, 2 at initial appointment, in 1 at a diagnostic clinic. Results, including correct/incorrect responses, and the child's interaction with the tool and clinician, are currently recorded in paper format whilst adherence to medical device regulation and data protection is completed. Feedback from the consultants and parents has been positive:

- It helps in creating a picture of the child. Whilst this includes results from the individual tests, additional information has emerged including how the child interacts with the clinician, such as when one child commented as the clinician expressed surprise at there being a crab in the treasure chest "are you afraid of crabs?", misinterpreting the clinician's emotions and facial expression. This mirrors observational information obtained in a full diagnostic assessment using tools such as ADOS and NEPSY, which can take 1-2 hours to complete.
- When used in combination with parental history and information from the child's educational setting this can help in deciding whether the child needs to proceed to full diagnostic assessment, or even in reaching a diagnostic conclusion.
- Parents like the fact that the doctor has been seen to "do a test for autism" and engage in seeing their child's ability either to perform the tests correctly (which can help in reassuring the parents) or to struggle, suggesting further assessment is required.
- Most children engaged with the familiarity of the Lego Mini-figures, the opportunity to play on a computer/iPad, and with the pirate theme.
- One consultant commented it was helpful having an observational tool to use with school aged children, mirroring use of observation of early development and play used in clinic with pre-school children.

- The app takes on average 10 minutes to complete, fitting into a standard 60-90 minute clinical appointment.

4. DISCUSSION AND CONCLUSION

Whilst this short paper reports very early results, it is encouraging that clinicians experienced in assessing children with possible ASD, have reported very positive experiences around use. The tool appears to provide information about the child's patterns of thinking; equivalent to psychometric testing used in full diagnostic assessment, and when used together with parental history and school questionnaire can help give a more complete picture of the child when deciding whether to proceed to diagnostic assessment. Parent feedback has also been very encouraging, one parent even asking if she could purchase the app to help teach her child to recognise different facial expressions. Initial impressions suggest a good correlation between performance on the tool and the presence of symptoms of possible ASD from parental history and school questionnaire. Further studies are needed to assess the performance of typically developing children, and whether this alters with age. This needs to be compared with performance in children with known ASD, and other conditions such as language disorder and learning difficulties that present with symptoms similar to children on the autistic spectrum. It will be important to ascertain, for example, whether there are different performance patterns in the different diagnostic groups, such as specific weaknesses in language based tests in children with language disorder. This early experience, along with discussion with experts in psychological testing for children, has highlighted a couple of areas that would benefit from adaptation, for example:

- Modifying the storyline used to test the child's level of understanding of tasks for second order theory of mind.
- Use of a clinical observational checklist.
- Potential incorporation of videoing child-clinician interaction.
- Recording reaction times on certain screens to help discriminate ADHD/ASD.

Early experience suggests that the tablet-based tool could become a useful adjunct to initial assessment of children referred with possible ASD.

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Effects of reintroducing haptic feedback to virtual-reality systems on movement profiles when reaching to virtual targets

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ABSTRACT

Virtual Reality (VR) has been shown to have significant impacts on the efficacy of rehabilitation, improving a patient's motivation and participation, as well as improving scores in functional assessments when used to enhance traditional therapy. However, movements in VR have been demonstrated to have significant differences in movement profiles whilst performing simple reaching tasks compared to their real counterparts. The lack of tactile perception in VR systems is often attributed to be one of the causes of these differences. Therefore, to investigate the degree to which the lack of haptic feedback impacts movement profiles in VR, we have reintroduced the sense of touch through vibration motors on the fingertips. Participants were required to reach to virtual targets, both with and without haptic feedback. Their movements were quantified using motion capture, and the virtual targets were rendered using the Oculus Rift. The motions to both targets were compared using a number of measures to characterize the velocity profiles. Preliminary results suggest that the reintroduction of haptic feedback improves performance based indicators in virtual reaching tasks, such as the time to complete a reach, and the stability of the reaching hand whilst touching the virtual target.

1. INTRODUCTION

Reaching is a fundamental action performed in everyday life, and the ability to do so is often diminished in the elderly, or in persons with neurological disorders, making upper limb rehabilitation of particular importance. Virtual Reality has been demonstrated to be an effective tool in such rehabilitation, with Henderson (2007) and Rand (2014) finding that VR based exercises were superior to their traditional counterparts.

Particularly during stance, reaching movements involve a complex coordination between movement and balance, performed by the central nervous system (CNS) (Hua 2013). The muscular activation and recruitment patterns of reaching movements in reality are well understood (Leonard 2009), though movements in VR have been demonstrated to not follow these same rules. The kinematic differences in VR movements have been found to negatively impact performance based indicators, such as accuracy and target acquisition time (Chen 2014). Multiple studies have quantified these differences, with Samini (2015) demonstrating that there exists biomechanical differences in the activation of the shoulder in VR reaching strategies, and Just et al. (2016) finding significantly higher pelvic velocity in motion capture data, indicative of a higher degree of postural instability. These findings suggest that VR seems to affect some elements in the feedforward control systems employed in reaching movements.

The differences found between VR and non-VR movements have often been attributed to a number of different factors, including display latency, visual inaccuracies, and lack of haptic feedback (Oculus VR, 2016). Haptic feedback in the form of placing physical objects at the same position as their virtual counterparts has been shown to slightly improve grip aperture and orientation (Cuijpers 2008), however, this approach is task specific, and does not allow for generic feedback to be provided for any virtual object. Therefore, we have integrated into our virtual reality set-up a vibration motor on the end of the right index finger to simulate the somatosensory response of reaching to physical objects.

This study aims to investigate the assumption that the lack of haptic feedback in VR systems contributes to the previously found differences in movement patterns, by providing a proof of concept trial on healthy participants, which may in turn be utilised to normalise VR reaching tasks in rehabilitation exercises.

2. METHOD

2.1 VR System Setup

The movements of participants were recorded using an XSENS MVN BIOMECH inertial motion capture suit, consisting of 17 microelectromechanical (MEMs) sensors placed on the body. The suit captures movements at 240Hz, and streams to the associated MVN Studio Pro software, where the sensor data is combined to animate a 23 segment kinematic model of the human body, with a latency of 20ms. The model data is then streamed as a collection of quaternion rotations into the Unity-4 game engine to control an avatar and mimic the movements of the user.

The Oculus Rift HMD is then used to provide an immersive visual projection of the virtual environment to the user, displaying the rendered scene from the position of the in-game model's head. The rotational and positional data from the HMD is used to control the direction orientation of the user's view.

Combining these two systems allows the user to move and look around the virtual environment; looking down, the user is able to see their virtual avatar's body, mimicking their real-life movements.

A simple circuit utilising an Arduino microcontroller and a small vibration motor was created to simulate the haptic feedback for the system. The vibration motor, measuring 10mm x 3.4mm and weighing 5g, was attached to the end of the user's index finger. Program code written in C# was created to activate the vibrational motor whenever a virtual collision event was detected, which occurred whenever the user touched a virtual object. The amount of force exerted on the virtual object by the virtual finger was calculated, and used to vary the PWM output to control the vibration motor.

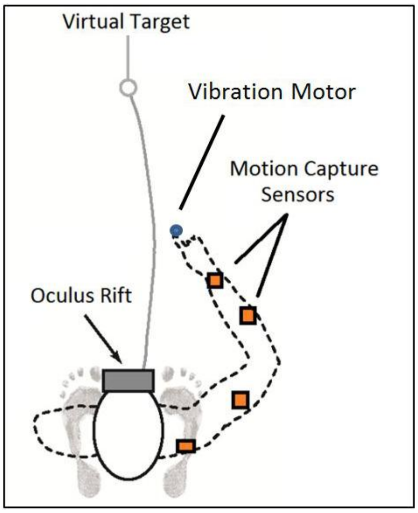

Figure 1. *Reaching to virtual target.*

This allows the user to experience variable haptic feedback when touching a virtual object; lightly grazing the object will give a light buzz, and jabbing an object with force will give a hard buzzing sensation.

2.2 Virtual Scene Setup

A simple scene was created in the Unity-4 game engine for the reaching task. The target was created to be a relatively complex polygonal object, which, combined with differential lighting techniques, has been shown to improve reaching performance in VR (Powell 2016).

The target was chosen to act in a number of different ways when touched in the virtual environment:

- Moves on a hinge joint to give visual feedback of the user's physical interaction with the object.
- Changes colour to indicate that it has been touched to give the user feedback that they have completed the task.
- A variable buzz is given to the end of the user's finger to simulate haptic feedback.

2.3 Procedure

Two healthy male right-handed participants (aged 20-25) were asked to reach to the virtual target in a standing position with a pistol grip. The pistol grip was chosen because it allows for the position of the end of the finger to be extrapolated from wrist angle and position without finger-level motion tracking. The target was initially calibrated to be positioned at 1.3 times the length of the participant's reach when feet are flat on the floor. The participants repeatedly reached for the target with their right hand (with the vibration motor attached to the index finger), held their index finger against the target for 5 seconds, retracted their hands to their chest, and held that position for 5 seconds. When haptics were enabled, the vibration motor buzzed in accordance to the level of force measured between the avatar's finger and the virtual target when touching.

The participants repeated this movement 30 times for each of 4 sessions (the initial 10 reaches of each session were removed to allow participants to become accustomed to the virtual environment). Each session was completed entirely with either the vibration motor enabled or disabled, with each participant completing 2 sessions of each. The first participant completed the session with haptics enabled, switching for each subsequent session, and the opposite for the second participant.

2.4 Quantifying the Data

In order to compare the results, a number of metrics were extracted from the motion capture data for each reaching movement, the means of which are presented here. The start point, maximum velocity magnitude achieved (Vmax), and the end point are used to construct an equivalent perfect reach, from which oscillatory movements and error are calculated. The velocity magnitude of reaching motions all exhibit a similar basic shape; a period of acceleration (activation) towards the maximum velocity, then a period of deceleration (settling) towards the target (see Figure 2). The periods of acceleration and deceleration should ideally be equivalent in length.

The relevant metrics extracted from the reach profiles for this study were as follows:

- *VMax.* The maximum velocity magnitude achieved.
- *ActGrad.* The gradient of the acceleration phase; how quickly the maximum velocity was achieved.
- *Time to Target.* The time taken to reach the target.
- *Symmetry Ratio.* The ratio between the duration of the acceleration and deceleration phases.
- *Settle MSE.* The amount of variability compared to the perfect reconstruction in the settling segment.
- *Holding MSE.* The amount of variation while holding the target position for 5 seconds.

The Settle MSE and Time to Target allow an effective characterisation of the difficulty a user experiences in acquiring the target, with virtual reaches exhibiting four times the variability, and two times the duration of their real counterpart reaches (Just 2016).

Table 1. *Participant #1 Results.*

Metric	Haptic Feedback Status	
	Enabled	***Disabled***
Vmax	0.995	0.917
ActGrad	0.019	0.018
Time to Target	1.675s	2.03s
Symmetry Ratio	0.355	0.310
Settle MSE	0.068	0.05
Hold MSE	0.0018	0.0028

Table 2. *Participant #2 Results.*

Metric	Haptic Feedback Status	
	Enabled	***Disabled***
Vmax	1.19	1.13
ActGrad	0.027	0.023
Time to Target	1.56s	1.80s
Symmetry Ratio	0.344	0.340
Settle MSE	0.053	0.046
Hold MSE	0.0094	0.015

3. RESULTS & DISCUSSION

As with previous studies (Just 2016), each participant exhibited a different base movement model, however comparison of haptic and non-haptic metrics displays a consistent impact of the introduction of haptic feedback.

The symmetry ratio, Vmax and ActGrad metrics all remained relatively unchanged by the introduction of haptic feedback. These metrics characterise the acceleration phase of the movement, and would suggest that this change does not significantly impact the initial activation of the reaching movement.

The deceleration phase of the movement profile, particularly the target acquisition, appeared to be improved when haptic feedback was enabled. The Time to Target was reduced on average by 14%, which confirms that participants were able to more quickly and accurately acquire the target with haptic feedback compared to visual feedback only. The Hold MSE was also markedly improved, with a 35% reduction in variability whilst holding the target position. This metric characterises the amount of instability, or 'hand waving', typical of haptic-less

VR systems. The large reduction in Hold MSE may be attributed to a 'light touch' sensory cue provided by the vibration motor, which has previously been demonstrated to improve balance even without providing mechanical support (Rabin 2013).

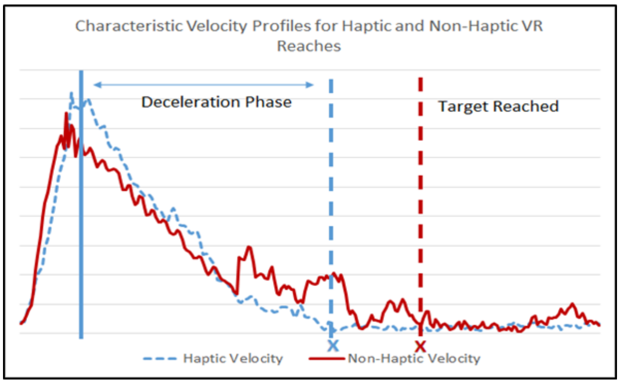

Figure 2. *Velocity profiles of characteristic results, X marks where the target was reached.*

4. CONCLUSION

These preliminary results demonstrate that the introduction of a replacement haptic feedback input improves performance based indicators in VR, such as the time to acquire a target. The main impact of introducing this feedback appears to affect the target acquisition phase of the reaching motion, as well as providing improved stability while holding at the virtual target.

Other facets of reaching profiles, which differ between VR and non-VR reaches, remain relatively unchanged, suggesting that haptic feedback is not likely to be the sole cause of these differences, though it does present a marked improvement on performance in VR. This proof of concept work provides promising results indicating that reaching exercises in VR may be made to more resemble their real counterparts by introducing simple haptic feedback. Further work is required to determine the impacts of such a system on a larger group, as well as the impact on the efficacy of motor rehabilitation.

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Step in time: exploration of synchrony and timing correction in response to virtual reality avatars for gait re-training

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ABSTRACT

This study investigates the use of virtual reality avatars as exercise cues for retraining gait. A feasibility test was conducted by asking participants to step in time with the avatar viewed through a virtual reality headset. We observed that a temporal perturbation (a speeding up or slowing down of one step cycle) applied to the avatar resulted in a significant corrective response in participants' own step timing. If this response can extend to spatial perturbations, we suggest that virtual reality avatars have the potential to assist in the targeted rehabilitation of neuromuscular or other disorders and retraining of gait post-surgery.

1. INTRODUCTION

Gait retraining is often required as an intense part of a physiotherapy or rehabilitation process, following neurological disease (e.g., Stroke) or serious musculoskeletal injuries. Using an auditory metronome to provide a regular beat has been found to be a simple and effective method for retraining the timing and coordination of gait following Stroke (Pelton et al., 2010). Similarly, the use of regularly timed visual stepping stones on a treadmill can be used to influence gait coordination (Bank et al., 2011). A key goal of retraining gait is to improve adaptability so individuals can quickly correct movements in response to a sudden perturbation or obstacle (Fonteyn et al., 2014). Gait adaptability training involves random phase perturbations inserted into otherwise regular auditory or visual rhythmic cues to force an adaptive response in the form of timing correction (Wright and Elliott, 2014). While this demonstrates the effectiveness of using sensory cueing for retraining gait, the abstract nature of the cues currently used limits the scope of their effect.

Evidence from research into social imitation (Rizzolatti and Craighero, 2004) and the phenomenon of spontaneous synchrony in gait (Zivotofsky and Hausdorff, 2007) highlights the potential for using the movements of a humanoid avatar to guide and influence user motion during rehabilitation but the effects of avatars in fully immersive 3D environments on the timing characteristics of gait have yet to be explored. Here, we describe the development of a novel method of visually cued training in the form of a full-body virtual partner in an immersive environment. We investigate whether participants are able to correct their steps to stay in time with the avatar following a perturbation to the avatar's gait and suggest it will be possible to develop more sensitive and targeted gait retraining methods using this virtual partner approach.

2. CLINICAL SIGNIFICANCE

The development of this method along with the proof of concept study opens up the possibility of using virtual partners to retrain gait in individuals following neurological disease or musculoskeletal injury. Having a representative partner to guide exercises could improve adherence to rehabilitation programmes and subsequently reduce long-term reliance on physiotherapy services. Importantly, we use a low cost consumer system that will allow it to be used in the home or community, as well as clinical environments.

3. METHODS

A volunteer (Male, age 37 years, height 1.8m) was recorded stepping on the spot using a 12-camera Vicon motion capture system. To set the tempo for each condition, the volunteer stepped in time with an auditory metronome with a beat interval of 450ms (Fast) and 800ms (Slow), at least 20% faster or slower than the normal male, self-selected inter-step interval of 543.4ms (Pietraszewski et al., 2012). Captured marker trajectories were mapped onto an avatar using Unity3D software (see Figure 1). The trajectory of one of the avatar step cycles was subsequently accelerated or decelerated by 15% to create a perturbation (Figure 2). Stepping in place was chosen as it allowed participants to naturally match their tempo to the avatar without external influences such as the speed of a treadmill or limited space within a gait lab. It is also a standard intervention to improve step height and speed in gait rehabilitation.

Figure 1. *An example of the virtual environment and avatar presented to the participant during the trial (left), and an image of one participant taking part in the trial wearing the Oculus Rift head mounted display and reflective Vicon markers for motion capture (right).*

In the main experiment, participants wore an Oculus Rift DK2 virtual reality headset to view the avatar, eliminating distractions and presenting a three dimensional 1:1 scale humanoid. They further wore reflective markers to capture their movements using a Vicon motion capture system. Participants (N=11, healthy males, age 23-39, right handed) were instructed to step on the spot in time with the avatar, unaware of the perturbation that took place in one of the step cycles. Participants completed 4 trials for each of the four conditions (Tempo [Slow, Fast] x Perturbation [+15%, -15%]). Trials included 30 steps each, resulting in a length of approximately 24 seconds for the slow condition and 13.5 seconds for the fast condition. The timing of the Oculus system was synchronized with the Vicon system using a hardware trigger. Heel step times of both the avatar and participant were extracted from movement trajectories to measure the timing errors (asynchronies).

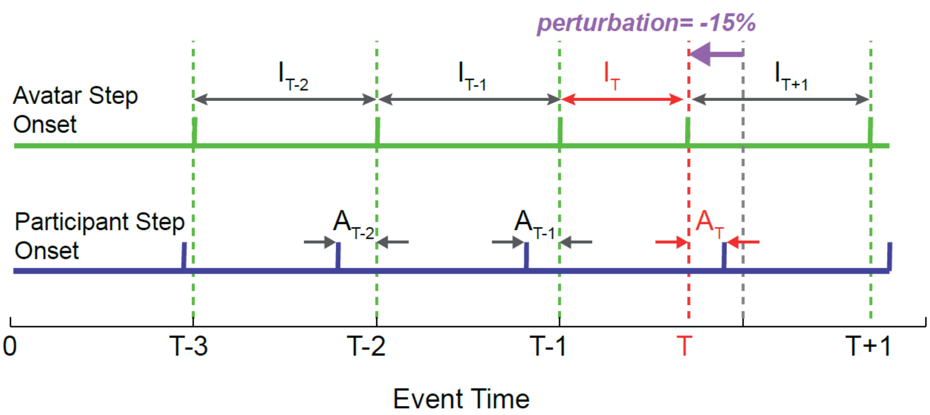

Figure 2. *A timing diagram illustrating the avatar steps (I) including a perturbed (speeded) step (I_T) and the measured asynchronies (A) between the participant's heel onsets and the corresponding onsets for the avatar.*

4. RESULTS

4.1 Hypothesis 1: Participants would be able to match the tempo of their steps with the Avatar's

For the Slow condition, participants' mean step intervals were found to accurately match those of the avatar. However, on average, participants stepped significantly slower than the avatar in the Fast condition ($p<.001$) (Figure 3), the difficulty in synchronising with the fast condition was commented on by some participants during the trial. We suspect synchronising to the fast rhythmic cue was difficult for the participants as the avatar had not been augmented with any auditory cues, such as stepping sounds, which have been found to lead to better synchronisation when compared to visual-only cues (Wright and Elliott, 2014).

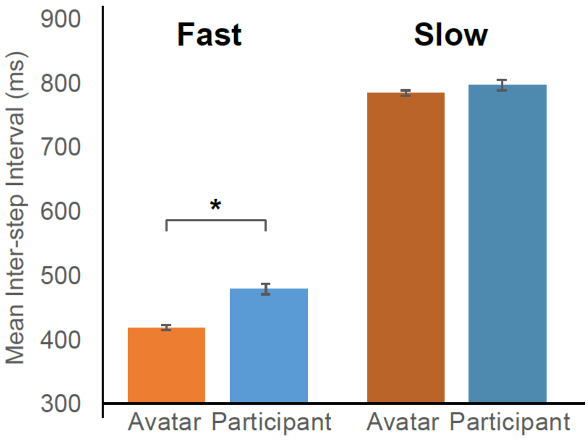

Figure 3. *Plot of mean Inter-Step Interval (ISI) of participants compared to the avatar cue for the Fast and Slow conditions, *A significant (p<.001) difference between avatar and participant step intervals indicated participants were unable to step in time with the fast condition. Therefore, these results have been excluded from the corrective response analysis.*

4.2 Hypothesis 2: Participants would be able to synchronise their steps with the Avatar's

Asynchronies, measured as the time between heel onsets of the participants and the corresponding onsets for the avatar, for the Slow condition were not significantly different from zero (Figure 4), suggesting good synchrony. However, variability (standard deviation) was high, indicating instability.

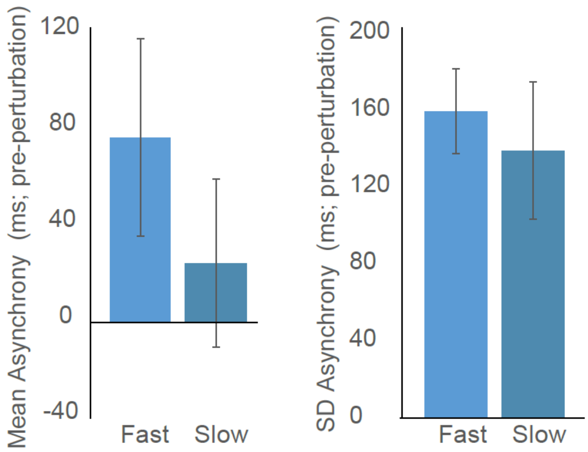

Figure 4. *Plots of mean asynchrony measured before the perturbed step (left), and the variability in synchronisation (right) for both fast and slow conditions.*

4.3 Hypothesis 3: Participants would correct their step timing to regain synchrony following a perturbation

Only the Slow condition was analysed. Relative mean asynchronies were calculated by subtracting the mean asynchrony pre-perturbation (T-5 to T-1) from all asynchronies in each trial to eliminate the baseline differences in step synchrony between participants. The post-perturbation response clearly shows participants corrected their step timing to regain synchrony (0 ms) with the avatar (Figure 5) even though the perturbation itself was imperceptible to participants. Recovery from a shortened interval was found to take longer (3 steps), on average across participants, compared to a lengthened interval (<2 steps).

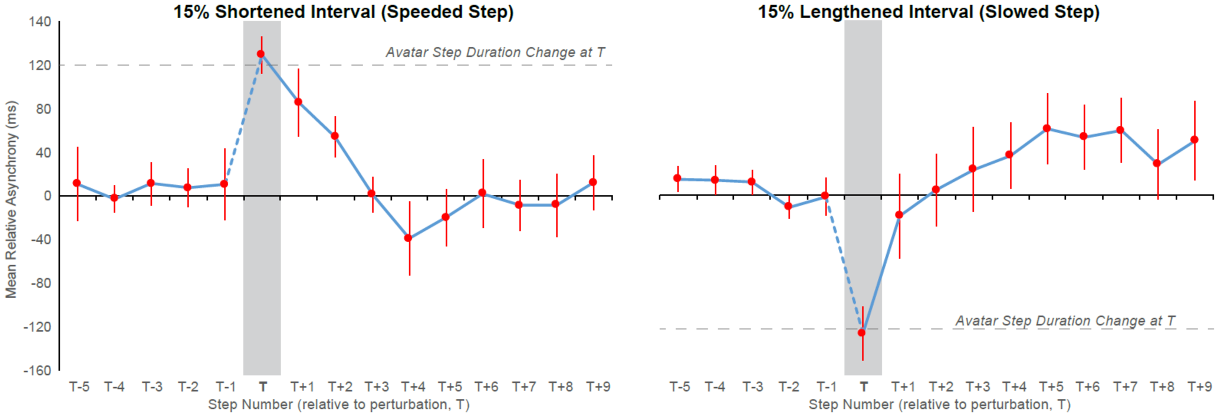

Figure 5. *Plots showing mean asynchrony across participants before and after the perturbation (step T). Participants corrected their step timing to gain synchrony with the avatar for both speeded (left) and slowed (right) steps.*

5. CONCLUSIONS

We have shown that an avatar's gait pattern in an immersive virtual environment (a head mounted display encompassing the user's vision) can be used to influence a person's temporal gait characteristics. When instructed to step in time with an avatar, participants are able to match the tempo of an avatar for slow exercises and, when a perturbation is made to the avatar's step timing, participants corrected their own timing to regain synchrony. Some issues remain, with participants unable to synchronise in the Fast condition. Future studies will investigate multisensory cues (e.g. auditory foot strikes) for improving accuracy.

Overall, this study highlights the potential of virtual partners, within immersive environments, to retrain gait timing and step coordination. If similar corrective responses can be elicited for spatial and complex perturbations, avatars could potentially be used to present personalised, targeted exercises, for the rehabilitation disorders affecting gait.

Acknowledgements: This work was supported by a WMG Internship for MR and WMG funded PhD for OK.

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Do user motivation and attention influence performance of a postural reaching task in a virtual environment?

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ABSTRACT

Practice in a virtual environment (VE) can enhance motivation and attention, but the relationship between these constructs and motor skill acquisition requires exploration. This study evaluated the impact of motivation (as measured by the Intrinsic Motivation Inventory) and attention to a task-irrelevant visual distraction (as measured by proxy via recall) on performance of a postural reaching task in a 2D VE in 27 young adults. Higher motivation was associated with higher scores, while poorer attention to task was associated with lower scores. Findings suggest that motivation and attention can impact VE practice; subsequent research will include retention and transfer tests.

1. INTRODUCTION

Virtual environments (VE) are increasingly common rehabilitation tools, yet much remains to be understood about how practice in a VE might enhance motor skill performance and learning as compared to practice in a physical environment. Motor learning is influenced by practice conditions during skill acquisition (Schmidt & Lee, 2011). Practice in a VE differs from the physical environment in ways that may facilitate motor skill acquisition and learning (Levac and Sveistrup, 2014). In particular, clients report high levels of motivation to practice in VEs (e.g., Tatla et al., 2013). While this enhanced motivation may indirectly enhance practice *quantity*, the extent to which motivation can directly affect motor learning processes to enhance practice *quality* is of particular interest (Lohse et al., 2016). Enhanced motivation is a prevalent rationale for VE use (Levac and Sveistrup, 2014), but few studies have explored the effects of motivation on motor skill performance and learning in VEs. Most recently, Lohse et al. (2016) found no relationship between motivation during practice of a new motor skill in a VE by healthy young adults and performance, retention or transfer of that skill.

VEs may support practice quality by enhancing engagement (Lohse et al., 2016). Engagement is defined as "an affective quality or experience of a participant in a task that emerges from focused attention, aesthetic pleasures, and perceptions of novelty" (Leiker et al., 2016, p. 4). Attentional resources and attentional demand may be feasible methods to objectively measure user engagement in VEs. Attentional reserve, as measured physiologically by EEG magnitude of event-related potentials (EVPs) to task-irrelevant probe tones, has been linked to self-reported engagement in a VE motor learning task (Leiker et al., 2016). The attentional demands of practice in a VE (as measured using verbal response time to an auditory tone) are higher than in the real world (Chen et al, 2015). Many tasks in VEs require dynamic movement, rendering EEG measurement of EVPs more challenging due to substantial artefact. VEs in which auditory elements are essential components complicate measuring responses to task-irrelevant auditory probes. As such, evaluating attention to task via a distracting visual stimulus could be a low-cost engagement proxy. Understanding whether attention to task relates to performance outcomes provides a rationale for further exploration of this type of measure.

The purpose of this study was to evaluate the impact of motivation and visual attention to task (as measured by recall of the contents of a distracting stimulus) on performance of a postural reaching task in a VE. The postural reaching task was practiced under 'easy' or 'hard' task parameter conditions. We hypothesized that 1) participants in the difficult practice condition would be more motivated and recall less of the contents of a distracting stimulus as compared to participants in the easy practice condition; 2) motivation would inversely correlate with recall; and 3) higher motivation and poorer recall (i.e., more attention to task) would be associated with better performance in both practice conditions.

2. METHODS

This cross-sectional study involved a convenience sample of healthy young university students without motor or cognitive impairments. The study took place in Northeastern University's Rehabilitation Games and Virtual Reality (ReGame-VR) laboratory using the Stability and Balance Learning Environment (STABLE; Motek Medical, The Netherlands), a virtual environment incorporating a force plate and motion capture cameras.

2.1 Procedures and task

Participants stood on a force plate holding a lightweight wand with a retroreflective marker in their dominant hand. Following calibration of reach distance and limits of stability, participants received standardized instructions to move their body, but not their feet, to 'unlock' a target (a circle covered by a gate) in the VE displayed on the screen in front of them and then 'touch' the target with their wand as quickly as possible. Successful touch required that the target be 'unlocked' (i.e., make the gate rise) by sufficient center of pressure (COP) displacement. COP displacement progress (i.e., gate movement) was indicated on the screen. Each trial involved a random sequence of 6 targets. Participants were randomly assigned to either the 'easy' or 'hard' practice condition, differentiated by time available per target and amount of COP displacement required. Participants practiced 100 trials of the task. Visual and auditory knowledge of results feedback was presented about success or failure of touch per target, and numeric knowledge of results feedback was presented per trial (trial score and cumulative score). Ambient task-related sound played in the background. A task-irrelevant visual stimulus (a soundless nature video) played on a monitor in the participants' left peripheral vision; the monitor was positioned such that participants could always see it in their peripheral vision but would need to actively turn their heads away from the VE in order to view the contents of the video.

2.2 Outcome measures

1. *Trial score.* Average time to successful 'unlocking' (via COP displacement) and touch for the 6 targets in a trial. Total score reflected cumulative trial score across 100 trials.
2. *Intrinsic Motivation Inventory (IMI):* The IMI is a 15-item questionnaire assessing participants' interest/enjoyment, perceived competence, effort, value/usefulness, and pressure/tension in completing a task. Questions were modified to be specific to the task.
3. *Recall of contents of a task-irrelevant video stimulus:* A study-specific questionnaire asked participants to recall the content of a soundless nature video that played in their peripheral vision during task practice. Participants identified the animals and scenes that made up the video; 1 point was given for each correct answer. We anticipated that participants who paid more attention to the video would be more likely to recall its contents.
4. *Self-report frequency of video gaze shifts:* We asked participants to rate the frequency with which they looked at the video using a 7-point Likert scale.

2.3 Analyses

Independent-t tests were undertaken for between group differences in each outcome measure. Pearson correlation evaluated the relationship between IMI and recall. Mixed non-linear regression models explored changes in score across trials. These models account for within-subject correlation and separate within-subject and between-subject variation of repeated trials on individual participants. IMI and recall scores were covariates in the mixed model to assess their relationship with practice condition and performance score.

3. RESULTS

Twenty-seven healthy young adults (10 males, 17 females) participated (14 in the 'easy' condition and 13 in the 'hard' condition). Participants had a mean age of 22.1 years (SD 2.1) years. There was a significant difference (mean difference [MD] = 3.5, standard error [SE] = 1.23, t = 2.845, p = 0.005) in mean trial scores between the 'easy' and 'hard' groups. The 'easy' group had an average higher score of 3.5 points over the 100 trials. There was a significant difference in total score between groups (MD = 277.6 pts, SE 50.2 pts, t = 5.524, p = .001) with the 'easy' group having a higher score. Figure 1 illustrates performance scores for all participants.

Average IMI score for all participants was 50.1% (SD 11.1%). There was no significant difference (MD = 8.27839, SE = 4.11247, t = 2.013, p = 0.055) between 'easy' (54.9 [SD 11.4]) and 'hard' (46.7 [SD 9.5]) group IMI scores. The mixed model analysis revealed a significant positive association between IMI scores and trial scores (t= 7.01, p = 0.001). For every 1% increase on the IMI, mean trial scores increased by 0.55 points. This association was significantly modified by group (t = -5.869, p = 0.001) with participants in the 'fast' condition demonstrating greater increase in mean trial score with increased motivation. Average recall score (on a 0-100 scale) for all participants was 33.7% (SD 21.7%). There was no significant differences between groups in recall scores (Easy mean: 32.7 [SD] 20.9), Hard mean: 32.9 [SD]: 23.2). However, there was a significant main effect of recall on skill acquisition. With every increase of 1 point in recall score (reflecting better recall of video contents), the mean trial score decreased by .2 points (t = -6.56, p = 0.001). There was no group interaction in this relationship. A significant main effect was observed such that as participants reported looking more frequently at the video, mean trial score decreased 2.02 points (t= -3.31, p = 0.003). Finally, there was no correlation between IMI scores and recall (r = .173, p = 0.409).

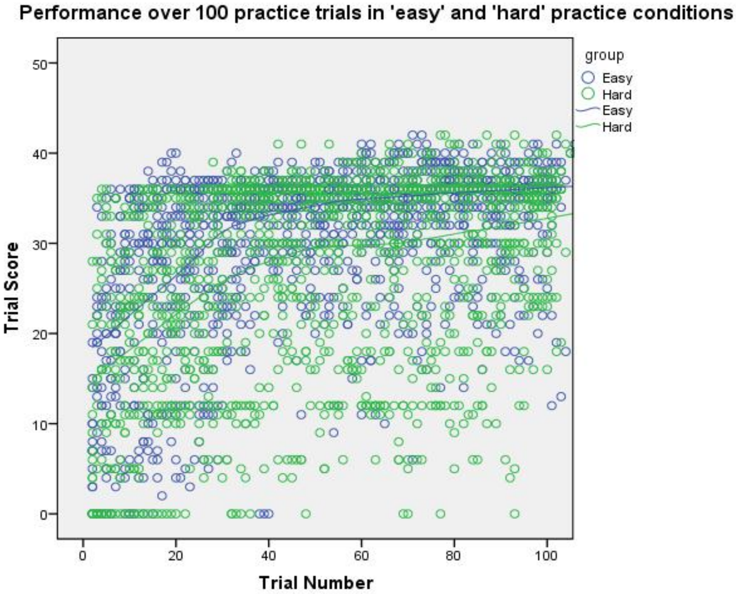

Figure 1. *Performance scores over 100 practice trials.*

4. DISCUSSION

This study explored the impact of user-reported motivation and recall of the contents of a distracting visual stimulus (as a proxy for attention to task) on performance of a postural reaching task in a VE in healthy young adults practicing under two challenge conditions. As this was the first evaluation of the task, the differing challenge conditions were utilized to inform task parameter selection for subsequent research purposes. As would be expected, participants in the easier practice condition performed better (as evidenced by higher scores). However, Figure 1 illustrates that neither practice condition posed significant difficulty for our participants. Although some between-person variability is evident, most participants had reached a maximum skill level following approximately 30-50 practice trials. This suggests the need for greater task precision to enable incremental increases in performance skill over time.

Despite differences in acquisition performance, we did not see hypothesized between-group differences in motivation or recall scores. We had expected that participants who practiced in the more challenging condition would report higher motivation to succeed and demonstrate less recall of the secondary video content (i.e., greater attention to the task) than would their counterparts in the easier condition. However, we did not elicit sufficient challenge during practice even in the more difficult condition nor did participants find the task highly motivating (overall mean IMI 50.1%, SD 11.1%). Despite evidence of a relationship between recall of the contents of a distracting video and task performance, participants overall could recall little about the distracting video (mean attention score 33.7%, SD 21.7%). Findings related to our attention proxy are clearly limited by the nature of this measurement, as recall challenges cognitive functions unrelated to attention. Some validation for the recall measure as a proxy for attention is evidenced by the fact that participants who self-reported looking more frequently at the video had poorer performance on the task. A further limitation is that the recall measure was time-related; given that we saw participants' performance plateau about midway through the testing session, it would have been valuable to more specifically capture whether attention to the video was more pronounced in the latter versus the earlier half of the practice session. Furthermore, we did not screen participants for an attention deficit disorder that may have impacted their attention to any task in any setting nor did we evaluate their memory recall capacities. Subsequent research will utilize more objective ways to measure attention to a distracting peripheral stimulus, including facial tracking to quantify screen views.

Despite these measurement issues and as hypothesized, motivation and recall (as a proxy for attention) were associated with skill acquisition. The effect for motivation was moderated by practice challenge, with participants in the hard condition increasing performance scores with greater motivation to a greater extent than participants in the easy condition. There was no effect of practice condition for the relationship between recall and skill acquisition. To our knowledge, this is the first study to demonstrate these effects for acquisition phases of learning a motor task in a VE. Lohse et al. (2016) did not find a relationship between self-reported IMI score and acquisition or retention of a motor task in a VE. Leiker et al. (2016) showed that attentional resources (as measured by EVPs on EEG) correlated with self-reported engagement, but no relationship with performance or learning was seen. The neurophysiological mechanisms by which motivation and attention might enhance the quality of motor learning of a new task are outlined by Wulf and Lewthwaite (2016) and include responses to positive experiences and strengthening of functional neural connections. Further exploration of valid measures of motivation, attention and engagement as potential '*active ingredients'* of practice in a VE that might enhance learning outcomes is important to provide evidence informing therapist decision-making about using VEs as compared to conventional real-world practice.

Our study is further limited by the fact that we did not measure subjective user engagement. Doing so would have supported exploration of the relationship between self-reported recall of a distracting stimulus (as an attention proxy) and engagement and provided more evidence to support or refute perusal of other measures of attention for their potential links to engagement in future studies.

5. CONCLUSIONS

Task challenge, motivation and recall of the contents of a distracting visual stimulus all related to performance of a postural reaching task in a VE. Although limited to motor skill acquisition rather than learning, this study adds to the growing body of literature about the significance of the user's affective state in VE practice settings. Future research will objectively evaluate visual attention, measure subjective engagement and evaluate the impact of these constructs on motor learning through delayed retention and transfer tests.

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How do the perspectives of clinicians with and without virtual reality/active video game experience differ about its use in practice?

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ABSTRACT

Little is known about clinicians' perspectives on the use of virtual reality (VR) and active video games (AVGs) in rehabilitation. We undertook an online survey of VR/AVG experience and learning needs in a sample of 1068 physical therapists and occupational therapists practicing in Canada. Nearly half (47%) had clinical experience with at least one system. While both therapist groups identified challenges and barriers, experienced therapists highlighted VR/AVGs' potential to increase patient motivation and engagement. Respondents without experience identified new potential avenues for VR/AVG use. Findings from this study will inform the content of open-access knowledge translation resources hosted at www.vr4rehab.com.

1. INTRODUCTION

Virtual reality (VR) and active video games (AVGs) are increasingly popular treatment interventions in a variety of rehabilitation practice settings and populations. Despite a growing evidence base (e.g., Finestone and Kumbhare, 2016), little is known about how clinicians perceive VR/AVGs as a tool for clinical practice. Gaining this knowledge is essential for both clinical knowledge translation (KT) and VR industry development. Understanding the perspectives of clinicians without VR/AVG experience can inform KT supports designed to enhance uptake. Information from clinicians with VR/AVG experience can further elucidate barriers and facilitators to VR/AVG use as well as identify clinical applications of this technology that can be evaluated in subsequent research. Perspectives from both groups can help the VR/AVG industry tailor their system packages and orientation to address therapist concerns and move the industry forward by designing games that meet therapeutic needs.

Current knowledge regarding clinicians' perspectives comes from small studies focused on specific VR/AVG systems, practice settings or patient populations. Previously identified barriers to VR/AVG adoption include lack of time to set up the technology and learn about its use, lack of funds to purchase systems or games, lack of space to deliver the interventions, and difficulty matching VR/AVG interventions with client goals (Glegg et al., 2014, Levac and Miller, 2013). Facilitators to VR/AVG integration include client motivation, clinician training and enhancing patients' social interaction with peers (Glegg et al., 2014, Levac and Miller, 2013, Tatla et al., 2015). To the best of our knowledge, no study has compared the perspectives about VR of clinicians with and without VR/AVG experience or surveyed clinicians from a wide range of practice settings.

2. METHODS

We undertook an online survey between February and August 2015 of physiotherapists and occupational therapists practicing in Canada who were members of one of 26 professional colleges or associations. The survey explored therapists' VR/AVG experience and learning needs with respect to integrating VR/AVGs into clinical practice. Quantitative findings related to the predictors of VR/AVG adoption, as well as to specific learning needs and preferences will be reported in a subsequent publication. The focus of this paper is on the results of an open-ended question that asked respondents for their perspectives on VR/AVG integration within rehabilitation. Respondents were divided into 'yes' or 'no' VR/AVG clinical experience. Two investigators (DL and PM) used conventional qualitative content analysis (Hsieh & Shannon, 2005) to code individual responses and create categories, illustrated with representative quotes, which were grouped within themes. Researchers approach conventional content analysis without preconceived categories; a full description of the method can be found in Hseih & Shannon (2005).

3. RESULTS

3.1 Participant demographics

With an estimated 20% survey response rate, the sample consisted of 506 physical therapists and 562 occupational therapists, with 47% having VR/AVG experience in a clinical setting and 54% having no VR/AVG clinical experience. Respondents worked in rehabilitation hospitals (26%), acute care hospitals (25%), and other settings, including residential or home care (14%), out-patient clinics (11%), community health centers (9%), and schools (5.5%). Most participants had experience with the Nintendo Wii and/or Wii Fit (73%), while only 7% had experience with the Microsoft Kinect; less than 3% of respondents had experience with other rehabilitation-specific systems (e.g. GestureTek, Jintronix, Timocco, CAREN, etc.). A VR/AVG system was available for use at work for 62.5% of participants.

3.2 Themes and categories

Seventy-six % of respondents with VR/AVG experience and 72% of participants without VR/AVG experience responded to the open-ended question. A subset of the full qualitative analysis is presented here. Three themes related to perceptions on VR/AVG use in clinical practice: Seeing Value, Seeing Challenges, and Seeing Potential. **Table 1** summarizes the categories within the qualitative analysis and the frequency counts for each group.

3.3 Differences in perspectives between clinicians with and without VR/AVG experience

Therapists with VR/AVG experience were more likely to comment that VR/AVG use provided benefits for patient motivation and engagement and supported use of motor learning principles. With respect to increasing engagement, one therapist stated: "*I believe using VR games is a meaningful, dynamic means of engaging clients in rehabilitation. Geriatric clients are often unable to continue engaging in physical activities previously enjoyed such as golf and bowling, with virtual reality they are able to engage in these activities in a different way that is still enjoyable.*" With respect to accordance with motor learning principles, one therapist commented on the feedback provided by the Wii Fit AVG: "*I use the Wii Fit balance board to provide people with visual feedback related to where there body is and the weight bearing status. I feel that it is an accurate way for them to be more familiar with their body postures and positioning.*" Respondents also reported that using VR/AVGs could increase therapeutic practice duration: "*When used for certain activities (i.e. balance), clients are able to stay engaged for longer periods of time than when using other modalities (i.e. wobble boards).*"

While respondents without VR/AVG experience were more likely to express challenges related to lack of training and access to VR/AVG systems, respondents with VR/AVG experience commented more specifically on issues related to its use in practice, such as the need for therapist supervision in guiding appropriate movement patterns, and the need for more accessible rehabilitation-specific games. For example, one therapist stated: "*...the overt sensitivity of some of the controllers allowed them to "cheat" on occasion and not use the full ROM I was looking for, which required diligence on my part.*" Another therapist stated: "*I would use VR/video games more if the challenges within the game could be graded more easily. It is difficult to match a client's ability with the game pre-set levels. Basic levels of games are often more advanced than clients are able to manage.*" More respondents with VR/AVG experience identified problematic issues related to logistics and practicalities, including technology issues: "*Technology is a great medium for treatment as long as it works well. I know when I am planning to use technology for treatment sessions I am quite frustrated if it malfunctions and I cannot get it to work correctly.*"

Table 1. *Qualitative analysis results presented as counts.*

Themes	Categories	YES experience (N)	NO experience (N)
Seeing Value	Enhancing patient fun and motivation	54	30
	Current/potential effective treatment for many therapeutic goals	42	24
	Enhancing patient engagement	20	24
	Promoting motor learning	13	3
	Enhancing therapist/patient relationship	2	0
Seeing Challenges	Inappropriate patients/setting	24	51
	Lack of time to set up or learn to use	21	20
	Lack of funds	13	10
	Need for therapist guidance to promote quality movement	13	0
	Need for more accessible, rehabilitation-specific games	12	0
	Lack of space	10	14
	Lack of knowledge	8	37
	VR should not replace real world experiences	6	5
	VR/AVG systems lack transportability	5	4
	Lack of evidence	3	7
	Concerns regarding lack of transfer to real world	3	6
	Screen time should be minimized	2	12
Seeing Potential	Use with lesser explored/potential populations (e.g. *mental health, chronic disease management, injury prevention)*	8	12

With respect to the theme of 'seeing potential', therapists without VR/AVG experience were more likely to identify creative potential new uses for this medium. For example, therapists stated "*It would be great to have a system for graded motor imagery when we are looking to break up chronic pain pathways and retrain the pre-motor cortex, visual centers etc. prior to retraining the motor cortex*" and "*I would love to have a VR teaching 'room' set up in order to help the patients I work with understand and apply principles of energy conservation in everyday activities. I think this would be a really unique and exciting way for people to learn and apply chronic disease management strategies and principles in a safe and controlled environment.*"

3.4 Similarities in perspectives between clinicians with and without VR/AVG experience

The greatest similarity in perspectives between groups was seen in identified challenges, such as cost, time, space, learning needs, characteristics of patients not being appropriate for VR/AVGs [e.g. young children, the elderly], and inappropriate settings [e.g. schools, homes]. Interestingly, lack of evidence to support VR/AVG use in practice was not mentioned frequently as a barrier in either group. Therapists in both groups mentioned concerns regarding lack of transfer from VR practice to real world skills. For example, one therapist without VR/AVG experience stated: "…"*However, the question will/would be – how well does playing the video game translate to real world real life? Using VR or games for treatment is interesting, but I would currently have a lot of trouble tying the use of that to a client's specific goals and determining if it is helping to achieve those goals.*"

4. DISCUSSION

As the first study to survey therapists with and without VR/AVG experience across a wide range of clinical practice settings and populations, our findings add to the existing knowledge about barriers and facilitators to VR/AVG use in practice, while confirming findings of previous small-scale studies. Our results also reinforce that similar issues exist in different settings, which provides rationale for larger scale KT implementation interventions that could be applicable across contexts. This study provides new knowledge about the perspectives of clinicians without VR/AVG experience, which can inform technology implementation efforts. Interestingly, more therapists without experience identified creative ways that they would like to see VR/AVG applied. These findings can inform VR/AVG developers looking for new populations or goals to target with games. Indeed, while developers may be focused on client end-users, therapists are the gatekeepers who decide whether or not games will be used, and systems need to suit both populations for optimal potential to enhance health outcomes.

Study respondents in both groups emphasized that VR/AVG use can enhance patient motivation and engagement, which is frequently presented as a rationale for VR/AVG use in the literature (e.g. Levac et al., 2012). This finding reinforces the need to measure motivation and engagement in clinical practice and the importance of research to investigate the characteristics supporting the learner's affective state as key 'active ingredients' of successful VR/AVG interventions.

Several respondents with and without VR/AVG experience were concerned about the 'virtual' aspect of these interventions and were clear that they preferred real life functional activities. However, other respondents identified that this medium allowed patients to practice skills that they could not otherwise accomplish in real life. Both of these issues - lack of ecological validity or transfer and opportunities to practice real life skills in safe and enjoyable environments – are important to further explore in VR/AVG research and development. Asking clinicians what they want and need and engaging current non-users in the development of new technologies is key and can support more tangible links between VR-based skills and real-world skills.

Study limitations include reliance on a single non-specific open-ended question. However, our findings – and those based on the survey as a whole – are informing the development of KT resources to be available on our website (www.vr4rehab.com). This website will be home to a range of online resources that are being designed to assist clinicians in keeping current with emerging research evidence on VR/AVGs in rehabilitation, in developing new knowledge and skills in applying VR/AVGs to practice, and in accessing networking and learning opportunities in the field. Interactive features will enable information exchange, and will help to build a community of practice for clinicians incorporating VR/AVGs as a treatment approach with clients across the lifespan in a variety of practice settings. We will soon administer the survey to therapists working in the US to further inform resource development and gain insight into the generalizability of the Canadian results to other health care contexts. Analyses will explore the relationship between employment setting and learning needs.

5. CONCLUSIONS

Physical and occupational therapists both with and without VR/AVG experience were able to identify challenges and barriers to use in practice, but those with experience were more nuanced about specific factors. The potential to increase patient motivation and engagement was highlighted by experienced therapists, as were specific challenges as to the therapist's role; however, respondents without experience shared potential new avenues for VR/AVG use. Study findings will inform development of resources designed to increase evidence-informed uptake of VR/AVG use in practice by therapists interested in integrating the technology and will target the challenges and facilitators to the technologies' use in rehabilitation that resonate with both novice and experienced users.

Acknowledgements: The authors wish to thank the physical and occupational therapists who participated in this survey as well as research assistants Rozlyn Young and Jessica Chu for their assistance with data management.

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Development of smart mobile phone application to monitor progress and wellness for Chronic Obstructive Pulmonary Disease patients

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ABSTRACT

A bespoke application (app), ‘KeepWell’, tuned to chronic obstructive pulmonary disease (COPD) self-management has been developed. The app facilitates goal setting, progress monitoring and personal reporting; features were informed by n=4 clinicians. Eight other clinicians tested usability by undertaking a list of interaction tasks and completing a usability questionnaire. Qualitative comments or problems experienced during the completion of each task were noted. Overall the participants reported high levels of usability. Features that scored consistently well were setting goals, self-reporting and viewing progress. Suggested changes were: setting and editing reminders and ensuring the manual information was consistent with the operation of the KeepWell app.

1. INTRODUCTION

Chronic Obstructive Pulmonary Disease (COPD) is characterised by airflow obstruction that is not fully reversible. Current treatment guidelines suggest a tailored and multidisciplinary approach including medical management of medications and potentially surgery, in addition to management of lifestyle behaviours such as smoking, exercising and diet (NICE, 2010). Referral to a Pulmonary Rehabilitation programme is recommended as a fundamental treatment for COPD. In Northern Ireland this is supplemented by a self-management education program developed to help people with COPD and their family to take charge and cope with their disease on a day-to-day basis in collaboration with their healthcare team. Living Well with COPD (LWWCOPD) provides the education programme (Borbeau et al. 2009; Earley et al, 2011).

There is an expectation that through Pulmonary Rehabilitation programmes, individuals will learn the skills, knowledge and confidence to self-manage their condition and maintain appropriate health behaviors after the programme has ended. Nevertheless, long-term outcomes of those who have attended Pulmonary Rehabilitation suggest that this may not be the case; there is a growing awareness that people with COPD may require greater assistance and support to successfully self-manage rather than as an optional extra. This has been aided by the LWWCOPD programme where patients can continue to follow the advice they have been provided with after their programme of Pulmonary Rehabilitation (Earley et al, 2011). For this reason we wish to extend the accessibility of these materials to supplement the current management of COPD after Pulmonary Rehabilitation by developing an Android mobile phone app called ‘KeepWell’ that incorporates the content of the LWWCOPD programme and helps the patient to develop self-management skills and self-health behaviours in order to improve disease control. The app is designed to harness the functionality of a smart phone and wearable device (Withings Pulse Ox: http://www.withings.com/uk/en/products) to enhance rehabilitation by enabling people with COPD to set goals, measure and monitor their physical activity levels and set reminders.

Therefore the aim of this work is to continue the development of the app on an iterative basis in collaboration with clinicians and people with COPD. This paper describes some of our collaborative work with clinical experts.

2. REVIEW OF LITERATURE AND APP STORES

2.1 Previous work in this area

Support for self-management programmes could be provided via a range of formats, for example, via internet, telephone, mentoring or coaching, and face-to-face individual or small-group-based activities (Borbeau et al, 2009). Some technology solutions have been developed to support the management of COPD and there are an increasing number of mobile phone apps available on app stores (such as Resp Assist, GOLD COPD strategy, COPDexchange) aimed to assist clinicians to manage their patients. We were not able to identify a previous study that has embedded an app into an existing Pulmonary Rehabilitation programme to support the patient to self-manage their COPD. With regards to support for the COPD patient, we have only identified computer-aided assistance for patients (e.g. Farmer et al, 2014; Johnston et al, 2014). These incorporated several aspects for self-management and support including treatment advice, physical activity monitoring, event detection and alerting. One planned study has included educational material in the form of text and video resources but has yet to report any results (Farmer et al, 2014).

3. DEVELOPING AND TESTING THE USABILITY OF THE APP

3.1 Preliminary meeting

An incremental prototype methodology was used in the formal technology development of KeepWell, and has been described elsewhere (Patterson et al, 2014). In order to ensure that the system was fit for purpose several structured meetings were conducted with four expert clinicians (n=2 from UK and n=2 from Canada) in order to get their views on the equipment, its usability from a clinical perspective, and make some decisions on how best to integrate the equipment into current COPD practice. At this stage a decision was made that KeepWell would have value as an adjunct to Pulmonary Rehabilitation, and assist people with COPD to self-manage their condition between visits with the health professional. It is envisaged that clinicians will provide the app and wearable device (for monitoring physical activity) during a face to face consultation during which the clinician and person with COPD would collaboratively set physical activity goals on the app. The focus of KeepWell is to assist the person with COPD to monitor their physical activity levels, measured via the wearable device and displayed on the app, be able to set step goals, and monitor their progress. In addition they would also be able to self-report their Borg Breathlessness scale on a daily basis, measured during their physical activity, and share this with the clinician. The Borg Breathlessness scale (called Borg scale from now) is a scale that asks the person with COPD to rate the difficulty of their breathing from number 0 where breathing is causing no difficulty at all through to number 10 where breathing difficulty is maximal. Clinicians advised that people with COPD should be active at a Borg scale of 3-4 (slight to slight to moderate difficulty breathing), so having a record of this will assist the clinician to support the person with COPD to set appropriate physical activity goals.

3.2 Usability of the KeepWell app

Further clinical opinion was obtained by asking clinicians to complete a series of tasks on KeepWell (see Table 1). Throughout the tasks, clinicians were permitted to consult with a printed manual, which explained the operation of the app, as needed.

3.2.1 Methods. The participants in the usability study were eight clinicians, six worked in the area of COPD management across Northern Ireland; and two were clinicians working in a research environment.

3.2.2 Procedure. Ethical approval was not required as the study was conducted under the auspices of Personal and Public Involvement, that is the involvement of expert clinician as specialist advisers in the design of the KeepWell app. Clinicians provided valuable knowledge and expertise based on their experience of patient and COPD management in the development of the KeepWell platform. No information was collected that could identify the clinicians involved, as the sole purpose was to evaluate usability of the KeepWell app. Clinicians were contacted by one of the research team to arrange a time and date for an individual meeting. The meetings took place across Northern Ireland at the clinician's place of work or at Ulster University. Before the participants began, the procedure was explained fully and they had a chance to ask questions. Once each clinician had completed the tasks (Table 1) and consulted with a printed manual explaining the operation of the KeepWell app they were asked to complete a usability questionnaire. Any qualitative comments or any problems during the completion of each task were noted.

Table 1. *Tasks completed during the clinical evaluation. PR=pulmonary rehabilitation.*

Task	Purpose
Clinician to complete the following steps • Put activity tracker together and position on wrist. • Launch app on mobile phone device. • Set a step goal. • Self-report a workout or Borg. • View progress within app including daily/weekly. • Create a reminder using date and time. • Change/edit reminder date and time.	To demonstrate how to wear and use the wearable device. To demonstrate overall function of app and highlight specific features. To obtain clinician opinion on usefulness of features.
Clinician to view educational materials	Check format of the included materials.
Clinician to review suitability of self-report workouts included in KeepWell.	Check suitability of workouts included.
Clinician to complete questionnaire.	Quantitative and qualitative feedback

3.2.3 Results. All the participants owned a smart phone, although the majority (63%) of these used the iOS platform. Overall, the participants rated the KeepWell app features highly (see Table 2) with lower ratings identified for the ease of the user interface. This might also explain in part the length of time that some of the respondents suggested they may need to learn how to use the KeepWell app which ranged from minutes (63%) to days/weeks (25%). Features that scored consistently well were setting goals, self-reporting work-outs or a Borg scale, and viewing progress. Suggested changes were setting and editing reminders and ensuring the information in the manual was consistent with the operation of the KeepWell app. All of the clinicians who worked in the area of COPD management (6/8) thought that the educational materials were suitable for use in people with COPD. Suggested changes were a search facility for education topics.

Table 2. *Likert Scale ratings of KeepWell app characteristics *1=Poor and 5=Excellent, ** 1=Difficult and 5=Easy, ***= Not useful and 5= Very useful.*

General Questions (n=8)				
	Mean	SD	Median	IQR
Please rate the look and feel of the app*	4	0.93	4	2
Please rate the responsiveness of the app*	4.38	0.74	4.5	1
Please rate the ease of the user interface*	3.75	0.89	3.5	1.25
Please rate the ease of menu navigation*	4.13	0.83	4	1.25
Please rate how easy the app would be to learn to use**	4.25	0.71	4	1
Please rate how comprehensive the instruction manual is**	4	0.58	4	0
Please rate how useful you feel this app is for helping to increase your physical activity level***	4.25	0.71	4	1
Please rate how useful you feel this app is for improving your knowledge about managing your COPD***	4.38	0.52	4	1

4. CONCLUSIONS

We have continued the development of the KeepWell app in collaboration with clinicians, in order to support people with COPD to better self-manage their condition. Clinicians rated the KeepWell app as usable, and considered that it could be an adjunct to Pulmonary Rehabilitation programmes, which are standard care in the UK. Some changes were suggested to improve usability, and these have been incorporated as part of an incremental prototype development methodology. Future developments of the app could include automatic generation of step goals based on previous physical activity performance and Borg scale scores, the porting of the app to iOS, and a search facility for the educational materials

Acknowledgements: We would like to thank the clinicians for sharing their views with us, Maria Garland who assisted with analysis and formatting of this paper, and Invest Northern Ireland for funding this work.

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Towards a novel biometric facial input for emotion recognition and assistive technology for virtual reality

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ABSTRACT

Preliminary work using facial EMG to identify facial expressions is reported in this paper. Ten subjects performed 14 different facial expressions following an agreed protocol. Facial EMG signals, measured from surface electrodes, were processed and analysed using a machine learning algorithm. Our system is able to differentiate facial expressions for assistive input to a high degree of accuracy (99.25%) and posed emotional responses with 100% accuracy. We conclude facial EMG technology has the potential for both assistive input and emotion detection and could replace conventional assistive input devices or video based techniques for use with VR technologies.

1. INTRODUCTION

Virtual reality (VR) has been called the 4th digital communications platform after personal computers, the internet and mobile phones. However, humans use facial expression to convey large amounts of information which infer their underlying affective states. These expressions have developed far more universally than language and six universal expressions; anger, disgust, fear, sadness, surprise and happiness have been described (Ekman et al, 1990). While affective states are suggested by physiological parameters (Picard, 2000) there is no substitute for spontaneous facial expression for research, product development and usability studies (Vandal et al, 2016).

Virtual reality headsets cover the area of the face traditional facial recognition software uses to detect expressions. Facial gestures can be used as an input or measured to assess real time emotional responses to stimuli. Facial gestures could be of particular benefit to those with limb disabilities who typically rely on current devices which are often based on hand tracking technology. Real time emotional response measurement has wide applications across media, research and commercial applications. The Facial Action Coding System requires video footage of the area obscured by a VR headset. By measuring facial EMG universal facial expressions can be identified and therefore affective states extrapolated.

Muscle computer interaction (MuCI) is a method of increasing engagement opportunities for people with disabilities through the use of alternate inputs or outputs. Traditionally based on muscle activation in the upper limb MuCI has been shown to be viable even for complex applications such as wheelchair navigation (Firoozabadi et al, 2008). Current research has shown facial EMG to be a viable method of MuCI (Hamedi et al, 2011, 2013, 2014, 2015). Even high spinal cord lesions will leave the facial nerve, the nerve responsible for facial expressions, intact. Therefore, demonstrating the potential uses for this technology as a method of human computer interaction.

Facial EMG analysis have been explored and refined using techniques including neural networks and machine learning. The high computational demands processing the data has the result that higher accuracy is achievable at the expense of performance speed (Hamedi et al, 2014). For these systems increasing the number of expressions which can be recognised increases the complexity of the task. Previous groups have considered up to 10 facial expressions, increasing the total to 14 including differentiating between left and right sided expressions could increase the applications of EMG as an input device (Hamedi et al, 2015). This development could encourage further research into other applications including medical rehabilitation of facial palsy.

Virtual reality provides an emotionally engaging and fully immersive visual environment for users. The nature of VR headsets obscuring the face disadvantages communication and social applications for VR. In this respect EMG is promising as sensors can be placed within the foam padding of existing VR devices potentially broadening the scope of VR interaction. Duel use of these sensors for both measuring emotional response and expression recognition for gesture control could widen the audience for VR and make it more accessible to those with disabilities.

2. METHODS AND MATERIALS

A range of facial expressions were considered, taking into account the action units (AU) of the facial action coding system (FACS) and how this could related to emotions and gesture input (Ekman & Frisen, 1978). For emotion recognition a subset of 6 expressions representing the emotional states of neutral, surprise (AU1, AU2), disgust (AU9, AU10), anger (AU4, AU5) and happiness were chosen. Happiness was divided into two states, a closed mouth (AU12) and a wider smile (AU6, AU12) representing a stronger emotional response. For assistive input a more comprehensive range of 14 expressions representing those that the majority of people could create voluntarily were selected. Figure 1 shows the final expressions selected for analysis.

2.1 Data Collection Protocol

The custom goggles with BIOMETRICS ltd. silver chloride (AgCl) electrodes (SEN3001) were positioned on subjects with freshly washed and dried faces to ensure good contact and standardised positioning. Five bipolar channels were used to gather EMG data. Maximum input of ±3V and resolution of 0.732mV. Power supply and current per channel was <4.6V and <20mA respectively. The wireless EMG system (BIOMETRICS ltd. DataLOG MWX8) can be worn on a belt and streams data via Bluetooth to a PC.

Expressions were recorded and performed in the same order using a standardised presentation on Microsoft PowerPoint. Subjects were shown a captioned photograph of the expression before and during each expression capture period. Expression capture was standardised with an audio recording signalling 10 seconds of rest a warning and 2 seconds of expression repeated 10 times for each expression. Subjects were instructed to hold a “neutral expression” between expression captures and asked not to blink in the capture period. Recordings took place in a single sitting without adjustment of the custom platform or positioning of the surface electrodes.

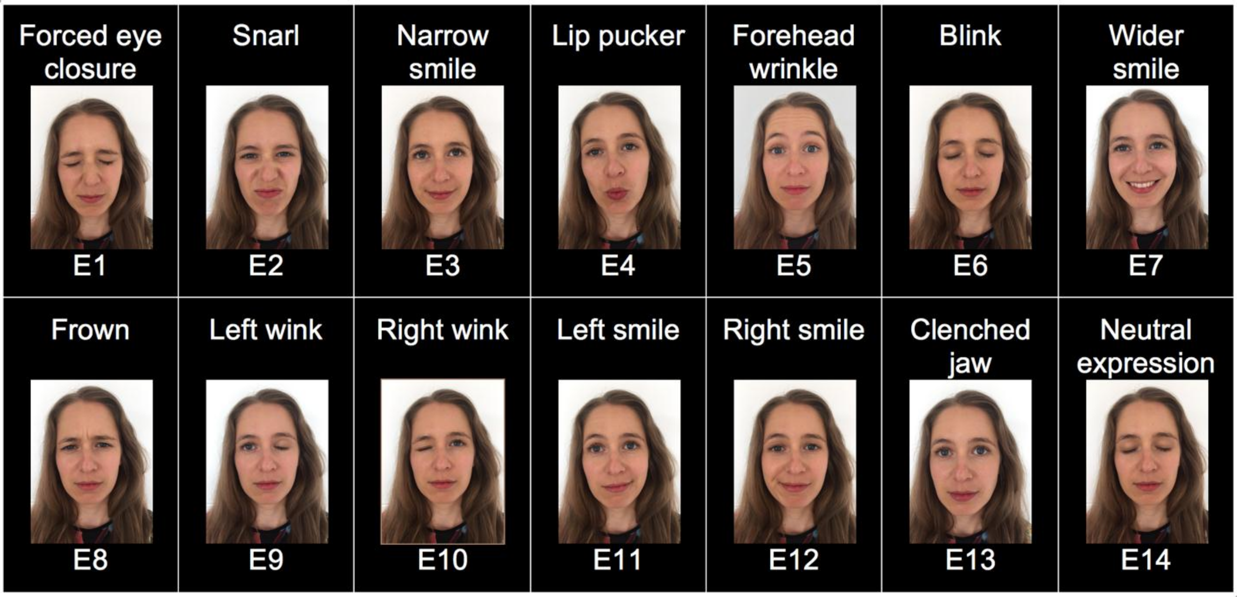

Figure 1. *Final expressions selected for analysis and coding. Snarl, Forehead wrinkle, Frown, Narrow smile and Wide smile have been selected to represent Disgust, Surprise, Anger and happiness respectively.*

2.2 EMG Pre-processing

Raw EMG data in all channels was passed through a 6^{th} order Butterworth band-pass filter in the range of 30-450Hz to envelop the most significant spectrum of signals. Facial EMG signals vary if the set up, including positioning, of the electrodes has been altered. The amplitude of the signals is therefore best measured in relative rather than absolute values. The filtered EMGs were therefore separately normalised using the maximum and minimum values of the EMG in that channel for each expression.

2.2 EMG Segmentation and feature extraction

To recognise the EMG patterns of different facial expressions, the most significant, discriminative features of the EMGs should be estimated. In pattern recognition the accuracy and success of the final performance is highly dependent on the quality of the signal features. Normalised EMG signals were segmented into non-overlapped windows of 256 ms length. Mean absolute values (*MAV*) were computed using equation 1 and extracted from each signal segment, where *N* is the length of the segment, *n* is the current segment and x_k is the current point.

$$MAV_n = \frac{1}{N}\sum_{k=1}^{N}|x_k| \tag{1}$$

2.3 Feature Classification

In order to recognise the facial expressions the extracted features need to be classified into distinct classes through a formal technique which provides a high level of accuracy at a low computational cost. This is desirable, particularly for assistive input technology. Previous studies have shown that least square support vector machine (LS-SVM) is a robust algorithm for classification of facial EMG patterns with a very short training time (Hamedi et al, 2015, 2016). This study used LS-SVM constructed by radial basis function kernel where the regularisation and smoothing parameters were set to 10 and 0.6 respectively. Multi-class LS-SVM was trained by considering One-Vs-One encoding method. The 10-fold cross validation strategy is used for classification evaluation.

3. RESULTS AND DISCUSSION

Of the 10 subjects 6 recordings were appropriate for full assessment of 14 expressions due to inability of some of the subjects to perform additional expressions. All 10 subjects were appropriate for assessment of posed emotional responses.

3.1 Assistive Input

Recognition accuracy varied between 98.03-100% for our system. More expressions were classified in this paper compared to previous publications, system performance shows our custom platform provides a stable framework to perfectly detect different facial expressions. Table 1 provides the confusion matrix of the system performance averaged over all the subjects. Forehead wrinkle, blink and left and right smiles were the most recognisable facial expressions within all subjects. Lip pucker was the most misclassified expression, mainly for left wink. On investigation this was an issue in one subject and was most likely due to electrode misplacement rather than similar signalling source.

Table 1. *Confusion matrix of the system performance averaged over all subjects.*

Predicted Class Label	Actual Class Label													
	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**	**E10**	**E11**	**E12**	**E13**	**E14**
E1	99.93	0	0	0	0	0	0.04	0	0	0	0	0	0	0
E2	0	98.81	0.11	0	0	0	0	0	0	0	0	0	1.17	0.08
E3	0	0.18	98.8	0	0	0	0	1.6	0	0	0	0	0.04	0
E4	0	0	0	96.88	0	0	0	0	1.47	0	0	0	0	0
E5	0	0	0	0	100	0	0	0	0	0	0	0	0	0
E6	0	0	0	0	0	100	0	0	0	0.58	0	0	0	0
E7	0.07	0	0	0	0	0	99.96	0	0	0	0	0	0	0
E8	0	0	1.09	0	0	0	0	98.4	0	0	0	0	0	0
E9	0	0	0	3.13	0	0	0	0	98.53	0	0	0	0	0
E10	0	0	0	0	0	0	0	0	0	99.42	0	0	0	0
E11	0	0	0	0	0	0	0	0	0	0	100	0	0	0
E12	0	0	0	0	0	0	0	0	0	0	0	100	0	0
E13	0	0.91	0	0	0	0	0	0	0	0	0	0	98.8	0
E14	0	0.11	0	0	0	0	0	0	0	0	0	0	0	99.93

3.2 Emotion Recognition

This is the first study investigating emotion detection for VR using Facial EMG. The placement of the electrodes round the custom platform mirrors current VR headsets while maximising muscle coverage. The system detects activity of the corrugator, frontalis, orbicularis oculi, nasalis, levator labii and zygomaticus muscles at different amplitudes for different expressions. As this section of our results focuses on emotion recognition and universal expressions all 10 subjects are included. Our system achieved 100% recognition accuracy for all 6 of our posed emotional expressions.

4. CONCLUSIONS

This paper is the first to report preliminary work using facial EMG signals to detect and identify facial expressions as a measure of an instant emotional response. Previous research has used video to measure facial expression and infer affective state. However, current methods are ineffective due to placement of VR headsets. We have demonstrated recognition of positive and negative expressions with an extremely high degree of accuracy with technology we feel could be integrated into current VR headsets.

Hamedi et al. (2011, 2013, 2014, 2015) have assessed different expressions but this is the first paper to recognise 14 different expressions, the largest number of facial expressions to be recognised by EMG as far as we are aware. Our system was able to differentiate between the expressions with a very high degree of accuracy, encouraging further research into this area. We plan to create an open hardware and software platform to enable other researchers and device makers to investigate opportunities for facial EMG in VR.

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©2016 ICDVRAT; ISBN 978-0-7049-1547-3

Physical therapists' opinion regarding the creation of a new virtual game to treat pelvic floor muscles dysfunction amongst children of school age

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ABSTRACT

The study aimed to investigate physical therapists' feedback regarding important points that should be added to a new virtual game application which will treat lower urinary tract dysfunction among children. This study used a questionnaire answered by ten physiotherapists, where the majority (80%) considered positively the idea of creating an application, while only 40% use technological devices in rehabilitation. With regards to observing patients progress, the majority (70%) reported a lack of tools that motivate the patient was the biggest problem. Based on that, we concluded that motivating tools are necessary to assist in pelvic floor treatment.

1. INTRODUCTION

Children with functional urinary disorders are those who have intermittent and involuntary contraction, or difficulty to relax the muscles of the urethral sphincter during voiding and may be associated with urgency, increased urinary frequency, recurrent urinary tract infection and vesicourethal reflux (Ladi Seyedian et al, 2014).

The treatment is based on pathophysiology and is initially focused on drug administration, education programs, hydration, constipation treatment, exercises for the pelvic floor muscles and biofeedback (Ballek & Mckenna, 2010). Biofeedback is an established therapeutic modality treatment of lower urinary tract dysfunction to be considered as a treatment choice (Schulman et al, 2001). Studies from the American Association International of Urology and Continence Society in children emphasize the importance of therapy expansion with the use of biofeedback (Koenig & Mckenna, 2011). However, the success of therapy with biofeedback depends on the motivation and dedication to the program, since it is based on repetitive exercises that need to be performed daily. In addition, children are not usually concerned about their urinary changes, and in addition they have trouble to focus on a specific activity (Mckenna et al, 1999).

Thus, the use of games becomes an important ally to rehab promoting a more interactive therapy and, consequently, a greater chance of adherence to treatment (Mckenna et al, 1999). One study shows that the use of biofeedback associated with the games demonstrated improved incontinence in 87% of children (Herndon, Decambre & Mckenna, 2001).

However, games should be designed in order to motivate the child to perform the therapy and promote the rehabilitation of the pelvic muscles. In this context, developing games that simulate certain activities can create a motivating environment for the rehabilitation process.

A physical therapy practice and rehabilitation in general has been strongly influenced by technological advances that society has experienced. However, even with this advent and the various discoveries in health care, much of the technological resources are not accessible to the entire community. Thus, it is important to consider devices that have a lower cost, greater accessibility and thus able to benefit a majority of the population.

Devices that start to be more widespread on the rehabilitation setting are Smartphones. They allow the creation of applications that are easy to implementation various activities, including in the home rehabilitation, and create animations and environments that can be more motivating for users (Chan et al, 2011). Moreover, they are already fully integrated in daily life, being accessible, portable and allow that data be transferred to professionals involved in rehabilitation, which can customize the exercises for each patient, as well as assess their progress in the activities (Franco et al., 2013).

However, the use of these tools needs to be designed according to the population that will be benefitted. It is important to understand which device will be used, how old is the person using the app, their living context, among other factors.

Thereby, the purpose of this research was to survey a range of physical therapists that will identify the need of applications to assist during their treatment of schoolchildren with lower urinary tract dysfunction. A subsequent purpose of the study is to create software (virtual game application) to train pelvic floor muscle among schoolchildren.

2. MATERIALS AND METHODS

This study used a questionnaire to understand physical therapists views on which aspects they consider relevant for further development of a game.

The study population consisted of physical therapists involved in the uropediatric area that works in different places. The proposal was to create an evaluation committee consisting of ten physiotherapists' judges. There is no consensus in the literature on the number of experts to be consulted. It is suggested a minimum of five and a maximum of ten specialists (POLIT, 2004).

Physical therapists were chosen because they are the professionals' who will work directly with this population. Only uropediatric physiotherapists were selected and they had at least a specialization course and had a minimum of two years of experience.

The questionnaire was designed specifically for this study. It consists of 22 questions with information about the use of technological resources in the service, what difficulties and strategies adopted to motivate the child during treatment, if the clients perform activities at home, how they evaluated whether the activity was done correctly, what are the treatment protocols they used and what suggestions they made for this virtual game.

The study was approved by the Ethics Committee from the Integral Medicine Professor Fernando Figueira Institute – IMIP was received. The survey was distributed by email. Prior to the study beginning participants were presented to the survey with an information sheet.

To evaluate the questionnaires we used descriptive statistics such as frequencies and percentages. All statistical analyses were performed using Statistical Package for the social sciences (SPSS Inc. Version 20).

3. RESULTS

Twelve participants agreed to participate on the study and 10 of these participants (83.4%) completed the survey. The characteristics for the 10 participants are reported in Table 1.

Table 1. *Participants' characteristics.*

Variables		**N**	**(%)**
Experience	Physical Therapist	5-10 years	(100)
Degree	Specialist	5	(50)
	Master	4	(40)
	Doctorate	1	(10)

According to the questionnaires analysed, 80% of professionals consider positively the idea of creating an app, but only 40% use some kind of technological device in your care and 10% justifies the non-use of technologies, arguing is unnecessary.

With regards to the difficulty in the progress of patients, the majority (70%) reported that the lack of tools that motivate the patient is the biggest problem, while 20% reported participants' indifference and 20% difficult in understanding the activity. In addition, 10% reports the behaviour of children and the immediacy of results required by parents. This item allows the marking of more than one option. Twenty per cent said they did not have trouble in treatment progress.

When asked about the strategies used during treatment to motivate, 60% reported to use recreational games and activities as strategies during rehabilitation. Ninety per cent considered homework important and 100% advise their patients to perform these activities. When asked how this activity is oriented, in 60% reported to orient by demonstration, 60% by verbal instruction, 70% by parental guidance, 70% by printed material and 20% in writing.

To investigate if the homework is being performed correctly, 10% reported to observe patient and exercise evolution satisfaction, 20% use biofeedback, 10% use daily micturition and urinary losses maps, 50% ask the patient to repeat activity in the office, 20% only question whether the patient is doing the activity and 10% consider the report of parents.

When analysing the number of repetitions, movement speed, number of series, phasic and tonic fibers contraction there was no consensus among participants. Sixty per cent reported that they would depend on the clinical status of each patient. Usually 80% of patients are satisfied with did their activities at home and 80% of physiotherapists reported that the patients almost always realize homework activity, while 20% reported that they rarely do. Ninety per cent of physiotherapists consider that the activity is the most important if done correctly and 10% did not express their opinion.

4. DISCUSSION

This is a pioneering research aimed to understand the needs of applications that will assist treatment of schoolchildren with lower urinary tract dysfunction to create a virtual game application for schoolchildren to train pelvic floor muscle. Questionnaires have shown the interest of these professional in applications for rehabilitation and the need for strategies to improve the patient's motivation to perform the therapy. However, despite the interest in the use of technological resources it is still not inserted in clinical practice.

One of the tools used in urogynecological therapy is biofeedback. When compared to, conventional biofeedback with one that presents activities like games, it is observed that despite the two methods are effective, when associated with the use of games they show faster results (Kaye & Palmer, 2008). The biofeedback associated with games is the preferred method in the institutions, because the child is more engaged in carrying out the activity and promotes more opportunities to get to the expected results. In addition, it enables the child to keep partially clothed during therapy, allowing for more comfort (Koenig & Mckenna, 2011; Palmer, 2010).

Besides the use of games as an alternative to a more motivating therapy, it is suggested that biofeedback could be designed to allow the treatment in the home environment, being more accessible to patients who live far from treatment centres' and it would also allow more intensive therapy (Koenig & Mckenna, 2011).

Moreover, one aspect of the questionnaire pointed out was a difficulty to prove if the exercise has been done correctly. Only biofeedback can guarantee that the contraction is correct. As an alternative to do this, there is a terehabilitation which is the possibility to conduct a therapy or an assessment outside the clinical setting (Mccue, Fraiman & Pramuka, 2010). It can assist the home treatment of patients (Durfee et al., 2009), since, in addition to improving motivation and engagement in the performance of activities, could allow home therapy without clinical supervision, reducing costs and facilitating access to services (Levac & Galvin, 2013).

However, there is a great difficulty in accessing these virtual reality devices at home as a way to improve therapy. A device that starts to be more widespread for rehabilitation are Smartphones. They enable the creation of applications that facilitate the implementation of various activities, including rehabilitation in the home environment, and create animations and environments that can be more motivating for users (Chan et al., 2011). Moreover, they are already fully integrated in daily life, being accessible, portable and allow that data be transferred for professionals involved in rehabilitation, which can customize the exercises for each patient, as well as assess their progress in the activities (Franco et al., 2013).

Another important point is the relative difficulty to standardize treatment protocols. Therefore, it is interesting that the virtual game allows adjustments of repetitions, contraction time, speed of movement and contractions of tonic and phasic fiber.

This study had some limitations such as not using a previously validated questionnaire. It was searched in databases and nothing specific could be found. Furthermore, the possibility of physical therapists suggestions allows for a better understanding of the app proposal. However, the involvement of professionals from other areas for better understanding of the concept of the virtual game is needed. To accomplish that, another study is undergoing to engage teachers and web designers for a better device design.

5. CONCLUSIONS

Based on the information collected in this study it was possible to understand the need of motivating tools to assist the treatment of pelvic floor. One of established therapies is biofeedback. However, it is important to think of easy access and low cost devices to promote rehabilitation, allowing the use of both in the home and clinical environment.

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Mobile application to increase consciousness and strengthening of the pelvic floor muscles

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ABSTRACT

This research included the development of a computer interface for capturing electromyography signals via Bluetooth enabling the transmission of data to mobile devices combined with a specific virtual gaming application to investigate the biomechanical characteristics of the pelvic floor muscles. The capture of data is performed via electrodes placed at specific anatomic pelvic floor sites. The game was designed based on the evidence available on consciousness and strengthening of the pelvic floor muscles, in addition to coordinating training of the muscles at different levels of demand, according to each user.

1. INTRODUCTION

The successful treatment of pelvic floor disorders depends on the disorder severity, anatomical and nerve integrity, as well as the type of training, motivation and patient adherence to therapy (Ferreira & Santos, 2011).

Therefore, it is necessary to develop strategies that increase motivation and patient compliance. In this context, Virtual Reality (VR) is presented as an alternative that can enhance motivation and adherence of individuals, allowing the creation of different scenarios and contexts with a computerized interface in real-time (Adamovich et al., 2009; Bruin, et al., 2010; Levac & Galvin, 2013).

VR systems can include smartphones and tablets which enable the introduction of a new concept: “mobile health” or mHealth. The World Health Organization (WHO) defines mHealth as health practice mediated by mobile devices (Kay, 2011). There are publications about some applications for smartphones and tablets in order to promote rehabilitation (Chan et al., 2011; How et al., 2013; Krpic et al., 2013).

Specific mobile apps can also be found focused on urogynecological needs of women, as is the application “Tät”. This application aims to treat urinary incontinence (UI). It has information about the UI, guidance on lifestyle and instructions for an exercise program for pelvic floor muscles that involves visual and audible commands, plus the opportunity to set reminders for carrying on such training (Asklund et al., 2014; Asklund et al., 2015). However, the current devices provide only a series of exercises, without presenting any tool to assess whether the exercise is being done properly and not monitoring the activity by the therapist.

In summary, this study aimed to develop a virtual game for training and consciousness of the pelvic floor muscles, inserted in a mobile application for the Android operating system devices. The proposal is that the virtual game allows patients to play during activities, interacting and controlling through instant feedback of what is being done, given by electromyography (EMG) surface and the transmission of electromyography signal through Bluetooth technology.

2. MATERIALS AND METHODS

This research included the development of a device, a computer interface for capturing electromyographic signals Bluetooth connection enabling data transmission to mobile devices (smartphones and tablets) Android operating system. In combination with a specific virtual gaming application to investigate the physiological and biomechanical characteristics of the pelvic floor muscles.

A portable system was developed that includes hardware and software capable of acquiring EMG signals for Android operating system. The hardware consisted of a board with an electronic circuit that acquire, conditions and transmits the electromyography signal via Bluetooth to mobile devices operating on Android. This equipment works as a central processor, storing the acquired user data and generating graphs and reports with the EMG signal. The device was projected with two channels to make possible the data acquisition through intravaginal probe or surface electrodes adhered to the perineum. Moreover, the electromyographic data were processed by mobile application game software developed specifically for the pelvic floor muscles.

The game was designed based on the evidence available on consciousness and strengthening of the pelvic floor muscles, considering the involvement of the fast twitch muscle fibers and slow twitch muscle fibers. Perineal exercise protocols with evidence in the literature involve contractions lasting from 1 to 4 seconds to fast muscle fibers and 4 to 10 seconds for slow twitch muscle fibers. Furthermore, it is recommended a ratio between contraction and relaxation of 1:2 for fast muscle fibers and 1:1 for slow muscle fibers. (American College of Sports Medicine, 1990; Morkved et al., 2003; Dumoulin et al., 2014; Ayeleke et al., 2015). In addition to respecting these peculiarities, the game was designed to respect the muscular capacity of each application user at different levels of demand.

The idea was to develop an interactive game mechanics in two dimensions (2D), the line definition of art and game interface, the integration between the device and the game and the version of the application generation game designed for mobile devices that operate on the Android system.

3. RESULTS

A portable system was developed including a hardware and software capable of acquiring EMG signals Android operating system devices. Data was obtained through electrodes placed on the pelvic floor, with two options for use: intravaginal probe and one pair of surface electrodes in three and nine o'clock position of the perianal region (Kirby et al., 2011).

Data was paired with the mobile application MyoPelvic, which was designed to be self-explanatory and intuitive. The MyoPelvic allows user registration, as well as provide write and visual information about the placement of electromyographic sensors. The user can choose the type of sensor to be used (internal or external) and when the user try to start a game, from the home screen, the application seeks the developed device and connects to it via Bluetooth. After connection, a screen appears that allows the user access to the tutorial that teaches you how to play the proposed game and offers two game modes: one mode to work fast muscle fibers and a way to work slow twitch muscle fibers. Before the game starts, the application provides a calibration moment. It consists in verify the signal characteristics of the user during both rest and contraction. The calibration also allows to check the sustained time of the contraction that the individual is able to perform.

The concept of the game was inspired by the mountain biking (uphill/downhill) and consists of a mechanical 2D platform where the user controls a cyclist who needs to travel as far as possible on a route up and down the mountains (Figure 1). The game consists of terrain undulations that must be transposed by the rider via the user input contraction. In both modes, the person who is playing must contract and maintain the contraction of the pelvic floor muscles until the rider can reach the top of the mountain, where there is a flag. As he passed the flag, the participant must relax the muscles that were contracting so that the cyclist can go down the mountain. The relaxation should last until the end of the descent, where there is another flag. The passage by the flag at the end of the descent indicates that the woman should contract the muscles again so that the cyclist can climb the next mountain, starting a new cycle of contraction / relaxation.

It is important to emphasize that the mountain ascent time is the time that the user was able to maintain the contraction during calibration and the down time will depend on the game mode. If the game mode is for fast fibers, the time of descent (rest) will be twice the time of contraction and if the game is to work slow fibers, rest time is set for the same time of contraction.

Game modes use the "perina" as a scoring system. The "Perina" are achieved during contractions of the pelvic floor muscles, which are equivalent to higher mountains. The amount of "Perinas" obtained by each user depends of the contraction time (more time, more Perinas) and the amount of mountains covered by the cyclist, i.e., the number of contractions.

The successful ascending mountain is provided by maintaining the force contraction during a certain period of time, both established during calibration. It was established that the failure was given by a decrease of more than 50% of the strength and leads the user to the end of the game. If there was no loss of strength during the match, the end was determined by passing the cyclist for twelve mountains, which corresponds to 12 full contractions.

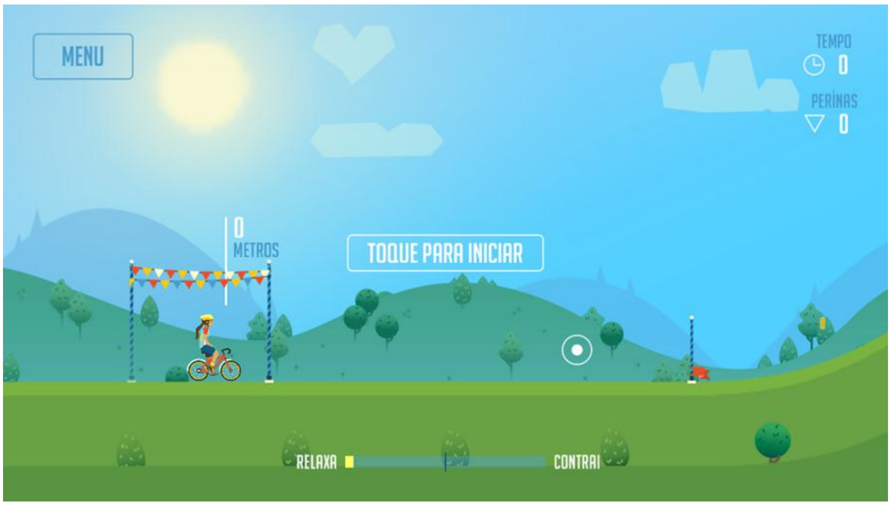

Figure 1. *Myopelvic application.*

In addition, it has a settings screen that enables the exchange of users and sending the history of the final matches information by email.

4. DISCUSSION

The developed game application was named MyoPelvic and has a game mode for the fast muscle fibers and another for slow muscle fibers. Both game modes involve the control by perineal contractions of a cyclist on a road that goes up and down in mountains. It works responding to variations of electromyography data received during times of contraction and relaxation of the pelvic floor muscles.

Searches on major scientific health databases have shown that there are no similar systems to the one developed on this study. However, there are two articles (Asklund et al, 2015; Nystrom et al, 2015) written about an application called "Tat", developed in Sweden. But this application, although has been an effective tool and easily accessible (Asklund et al, 2015,. Nystrom et al, 2015), has only informational purposes and does not provide the user with a reliable feedback of what is being done.

Advanced searches for major mobile application stores has shown that there is a range of applications such as Kegel Exercises, Kegel Trainer, MaxKegel, Pelvic Floor Exercises and Kegel, EjerciciosKegel and Kegel Bootcamp. The main purpose of these applications is to assist the training of the pelvic floor muscles through exercises proposed series. However, these applications seem to have the same weakness as the previous applications found: they do not provide the feedback to the user about the proposed exercises.

Given this gap, some products have been launched in the market by offering feedback to pelvic floor exercises performed in the integrated mobile application systems. They are: Kgoal, Elvie, Skea - Smart Kegel Exercise Aid and Magic Kegel. All these products have a hardware and software system, which involves a silicon device, designed to be inserted into the vaginal canal, and a mobile application. Nevertheless, the information available on these devices are still superficial and commercially based, without evidence that exercise protocols respect the particularities of the pelvic floor muscles and the characteristics of each individual who use these systems. In this context, the MyoPelvic application stands out as a new virtual game based on current scientific evidence on strengthening and awareness of the pelvic floor muscles.

Another important aspect to be considered is related to the difference between the sensors used. While MyoPelvic responds to signals from electromyographic sensors positioned in the perineum, the various systems on the market use intravaginal pressure sensors. However, since the intravaginal pressure is influenced by the activity of the abdominal muscles (Madill & McLean, 2006), the feedback promoted by pressure systems may overestimate the quality of contractions of the pelvic floor muscles and reduce the specificity of the muscles involved in the exercise.

It stands out also that the MyoPelvic application involves capturing electromyographic signal, considered more refined than the pressure signal for enabling the extraction of different important data such as RMS and frequency parameters. Therefore, the developed system appears as a prototype to be improved, but has the potential to further assist the treatment of patients with pelvic floor dysfunction by providing the electromyographic data to the therapist.

The lack of studies comparing different devices systems such as MyoPelvic prevents the development of discussions to a higher level that points advantage between systems. New research studies are suggested to gather the user satisfaction and to evaluate the usability of the MyoPelvic. It also suggests the development of clinical trials to test the efficacy of system utilization in populations with different disorders of the pelvic floor and to test the effectiveness of the MyoPelvic as a telerehabilitation tool.

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Kinect sensor controlled game for early diagnosis of visual problems

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ABSTRACT

A serious game was designed for early (preschool-aged) vision-test at home or in kindergartens. It was created with Windows Presentation Foundation framework. This framework is a good choice for developing vision-test game modules, as they can be easily accessed from one main application. The game module is a “Drag and Drop” game, which can be controlled with Kinect v2 sensor. The game is designed to take various objects along the tracks to the suitable finish goal. This type of game will help the user discover visual acuity problems. The game monitors that how long it takes to complete the track with different difficulty settings, while storing the results.

1. INTRODUCTION

Eye exams for children are extremely important, because 5 to 10 percent of preschoolers and 25 percent of school-aged children have vision problems (U.S. Preventive Services Task Force, 2004). The visual acuity test of preschool and primary school children is a big problem. Since they cannot give an answer to the question, whether they can see something clearly? They are not fully familiar with their environment yet, therefore they cannot answer to every question. For testing preschool age children’s vision problems, the ophthalmologist shows a table. Usually a figure, like a capital ‘E’ letter is on this table in Hungary, but the ophthalmologist shows this table in different positions. It means that the capital ‘E’ letter’s opening is in left-, right-, up- or down position. This kind of testing, the Kettesy table (Süveges, 2010), and Snellen Table is used in other countries (Segre, 2015).

Some common eye test used for young children: LEA symbols, Retnoscopy, Rnado dot stereopsis test (Heting, 2015). Furthermore, nowadays there are a lot of smart phone applications. Stanzel and Meyer (Stanzel, 2012) used search engines, developers’ websites and webstores for screening with key words such as “smartphone”, “medical apps” and “eye-test”, after it they made a survey too. The result of their research is that the increasing distribution of Smartphone “apps” in ophthalmology may have the potential to facilitate patient treatment, data management and communication.

The aim of our research is to develop an interactive and attractive game based on new technologies for preschool children. This way, parents and kindergarten teachers could examine children’s vision playfully. The adult persons could realize the children’s visual acuity earlier by using this game, and in such cases they can take specialist’s examination where the ophthalmologist can intervene. Early diagnosis is very important for the untimely therapy.

2. STATE OF THE ART

2.1 Visus

In the early 1980s computers became more available in schools for visually impaired children (Blenkhorn, 1986) and a significant number of software systems were developed to support the assessment and training of visual skills (Blenkhorn & Tobin, 1983, Spencer at al., 1987). Although these systems tended to be used somewhat more informally and less systematically than packages such as “Look and Think”, many teachers reported positive experiences with the children. More recently systems have been produced for more modern computer systems. Such systems can be used to support a subset of visual skills, namely: awareness of vision as a sense, localization of visual stimuli, colour vision, tracking and hand-eye co-ordination (Blenkhorn & Evans, 2001).

The number of partially sighted children increases year to year. Several games of different types (action, adventure, exploration…) have already been developed (Sik Lanyi & Lanyi, 2003), (Sik Lanyi et al., 2005). There are also many instruments to be used by partially sighted people, including some solutions (Kobayashi & Watanabe, 2002), but not for very small children.

The *visus*, i.e. how well the person can read the letters of a Snellen Table or other visual acuity test, of children can be improved by early training of their vision. Our programs build on the remaining vision of these children and help them in learning how to fixate on given targets and use their eyes to search for details. This is very important as with proper training the visus of the children can be improved considerably. It is probably unnecessary to stress that for any person to be able to live a full life it is very important to have a vision as good as possible. Neither with the best methods of presentation nor with the most sophisticated equipment can one fully compensate for a loss of vision. Thus, it is of great importance to rehabilitate the vision of the children, and this has to be started at a very young age. This will help them to learn more easily in school, to get more information by roaming on the WEB, and finally as an adult to find a job more easily. Later, if these children go to school, they have to use computers and Internet too. Most of the visual impaired users use text-based web browsers, or read online content with a speech-based system. Some people are able to read the screen content only with increased font size.

Before proceeding it is essential to clarify some concepts, which are necessary to understand the meaning of partial sightedness and visual impairment. The term visual impairment is used to describe a slight or serious reduction of sensory function resulting from damage suffered by visual organs. Visual function includes specific perceptive abilities (visual sharpness, field of vision, sensitiveness to contrast, etc) each of which contributes in differing amounts to define the threshold of optimum perceptive functioning. As Khan and Chowdhury stated: “For example, visual sharpness and field of vision are two fundamental parameters, according to which a disability is recognized, in a proportionate measure. Visual sharpness means the ability to “discriminate” in maximum contrast conditions, it is a question of evaluating the individual’s ability to perceive the details of an image placed at the centre of his field of vision and in particular an object being looked at, it is measured from a distance and is evaluated with the best correction for each eye. If the eyes are both functioning, there is an improvement of visual sharpness (visus) in binocular vision” (Khan & Chowdhury, 2004). The loss of vision is a psychological trauma to the partially sighted, nevertheless, they would like to conduct a lifestyle similar to those with normal vision. To give them a chance of performing similarly to those with normal vision, they have to be helped in developing their skills; they have to be supported in their learning.

2.2 Kinect for Windows v2

The main usage areas of Kinect are retail, therapy, healthcare, education and training. Kinect for Windows v2 is a new kind of camera that can see in 3D. It has an RGB camera, depth sensor and multi-array microphone running proprietary software. This software provides full-body 3D motion capture, facial recognition and voice recognition capabilities. Above these it has a traditional video camera and an infra-red (IR) camera too. The new Kinect can recognize that a person is in front of the sensor and what position their body is. Moreover it has a software controllable directional microphone and speech recognition technology, etc. The Kinect for Windows Software Development Kit (SDK) 2.0 enables developers to create applications that support gesture and voice recognition, using Kinect sensor technology on computers running Windows 8, Windows 8.1, Windows Embedded Standard 8, and Windows Embedded Standard 8.1.

3. THE GAME

3.1 System requirements

The framework of the game uses a Kinect for Xbox One device and an Adapter for Windows hub for the connection to the Computer. The recommended system requirements are:

- Microsoft Kinect sensor for Xbox One
- Microsoft Windows Adapter hub
- Kinect for Windows SDK 2.0
- Windows 8, 8.1, Windows Embedded 8 or Windows 10 operating system
- 64-bit (x64) processor
- Dual-core 3.1 GHz or faster processor
- 4 GB of RAM
- Dedicated USB 3.0 port
- DirectX 11 compatible video card

In addition to the above recommended system requirements, Microsoft made available an application, which helps to identify that the Kinect v2 meets the requirements of the computer or not. This application is called Kinect Configuration Verifier tool.

3.2 Using the frame-software

3.2.1 Main menu. On the main menu (Figure 1) the user can find the Play-, the Profiles-, the Settings-, History- and Exit options. The main menu is arranged in a horizontal menu, where the user can scroll through items like in the Windows 8 operating system. First, the user has to make the relationship with the system. For this operation the user has to raise his/her hands. It was very important to build natural gestures into the framework of the game, because the users are children.

Figure 1. *The main menu.*

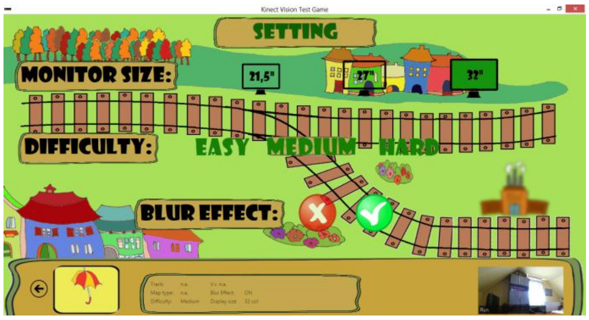

Figure 2. *Settings.*

3.2.2 Settings menu. Figure 2 shows the settings menu. Here the display size, the level of difficulty is adjustable, and the blur effect feature can be turned on. For this function an example (a track) with an object is visible in the background. Those keys are always available for the user, with the help of which they can make some changes to the settings.

3.3 Using the game

3.3.1 The purpose of the game and using the game. The goal of the game is to put an object (for example a car, a privateer, train) from the left part of the screen to the finish, which is on the right part of the screen. Each track has a good route and a bad route. During the game, the user must choose between the two routes, where he/she moves the vehicle. It depends of course on the visibility of the finish and the routes. The size of the movable objects and the finish is reduced by twenty percent on the next level. So the player will find it more difficult to distinguish the objects.

3.3.2 Controlling the game. The game can be controlled with two input devices: Microsoft Kinect for Xbox One and a traditional mouse. The user can switch between them during the game too. If the user would like to controll the game via Kinect sensor he/she just has to raise his/her hand. In this case it will automatically detect the Kinect and establish a connection between the player and the software. If the gesture was done properly, a hand appears in the center of the screen as a cursor.

After the connection, the player can move the cursor on the display everywhere by moving his/her hands. He/she has to “catch” the vehicle on the left side of the screen and move it on the track to the finish without letting it off. For catching the vehicle the user has to close his/her hand. If the gesure was made properly, the “hand” cursor is closing on the screen as well. For releasing the vehicle the user has to open his/her hand.

3.3.3 Screen of the play. The following elements are on the user interface of the game (Figure 3):

1. Vehicle – the child has to move it to the finish
2. Bad option – if the user drawes the vehicle here, it is false results
3. Good solution - if the user drives the vehicle here, this level is succesfull and the user can move on to the next level
4. Kinect v2 color camera screen - to indicate the location of the user
5. Status - displays the status of the sensor Kinect v2.
6. Information - it provides giving information to the parents for example from the applied settings
7. User icon image - the current user ID appears here (kindergarten symbol)
8. Back button - the user can exit from the game

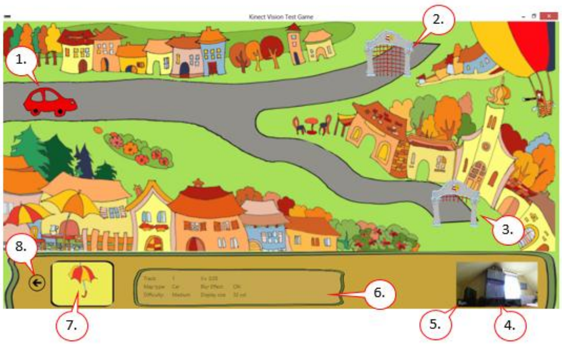

Figure 3. *Screenshot of the game.*

4. CONCLUSIONS

A Kinect controlled game was developed for early (preschool aged) vision-test. The parents or the pre-schools' teachers can use it at home or in the kindergartens. It was created with Windows Presentation Foundation (WPF) framework. The game has a very user-friendly user interface. The children's task is only catching an object and pushing it to the the final position of a track. The game is designed to take various objects (vehicles) along the tracks to the suitable finish, but the visibility and the size of the objects and background pictures and tracks are changed in each level. This type of game will help the user (parents and pre-school teachers) to discover the children's visual acuity problems. The game monitors the completing time of a level and the difficulty settings too. The results and the settings' data are stored in a database. The game was tested by adult users and children. Our future plan is making opthalmologist tests and compare the results of the game and the opthalmolgist's tests.

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Development and validation of haptic interface for deaf-blind horseback riding

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ABSTRACT

We present a haptic interface to help blind and deaf-blind people to practice horse riding as a recreational and therapeutic activity. Horseback riding is a form of animal assisted therapy which can improve self-esteem and sensation of independence. It has been shown to benefit people with various medical conditions including autism. However, in the case of deaf-blind individuals a therapist or an interpreter must stand by at all times to communicate with the rider by touch. We developed a novel and low cost interface which enables blind and deaf-blind people to enjoy horseback riding while the instructor is observing and remotely providing cues to the rider, which improves their independence. Initial tests of the concept with an autistic deaf-blind individual received very positive feedback from the rider, his family and therapist.

1. INTRODUCTION

Animal assisted therapy (AAT) is practised to improve physical and mental health of people with various conditions. It was found that AAT has positive effects on attention deficit hyperactivity disorder (Busch et al., 2016). AAT provides significant improvements in behaviour and social interaction in humans with autism spectrum disorder (ASD). Children with autism who practiced horseback riding exhibited greater sensory seeking, sensory sensitivity, social motivation, and less inattention, distractibility, and sedentary behaviours (Bass et al., 2009).

Though horseback riding therapy may be beneficial for individuals with various conditions, some disabilities prevent the disabled to take part, as in the case of blindness and deaf-blindness. The World Health Organisation reports the world's blind population is about 39 million. Among those, it is estimated that there are around 50,000 deaf-blind individuals in USA alone (Caporusso et al., 2014). The barriers in communication and social interaction caused by deaf-blindness can lead to a number of health related difficulties, including high risk of depression, cognitive decline, developmental disorder in children and psychological distress (Dammeyer, 2014).

Hence development of novel technologies for blind and deaf-blind users is crucial as it can enable them to take part in various activities. In recent years, haptic interfaces have been developed that enable communication for the deaf-blind (Caporusso et al., 2014, Nagel et al., 2005). To our knowledge there is no low cost commercial solution for spatial navigation that provides a simple input interface and can be easily used by a deaf-blind rider and a riding instructor. Therefore, we propose a novel haptic communication system giving a deaf-blind person an ability to command a horse independently, rather than through physical guidance of the instructor. In this work we report the results of the validation trials which we believe is the world's first application of haptic technology for deaf-blind horseback riding.

2. WEARABLE INTERFACE FOR DEAF-BLIND HORSEBACK RIDING

In the conventional way of deaf-blind horse riding the rider either passively rides the horse as it is being guided by the instructor, or the rider controls the reins while the instructor communicates spatial cues by touch. Because the rider cannot experience the sense of control and independence, this conventional therapy cannot produce maximal positive therapeutic effect on the rider, who remains dependent on direct proximity of the therapist. We propose to use a simple set of vibrotactile instructions generated by a wirelessly controlled tactile actuators. Our system includes two vibration motors (tactors) worn by the rider on the upper arms which are wirelessly

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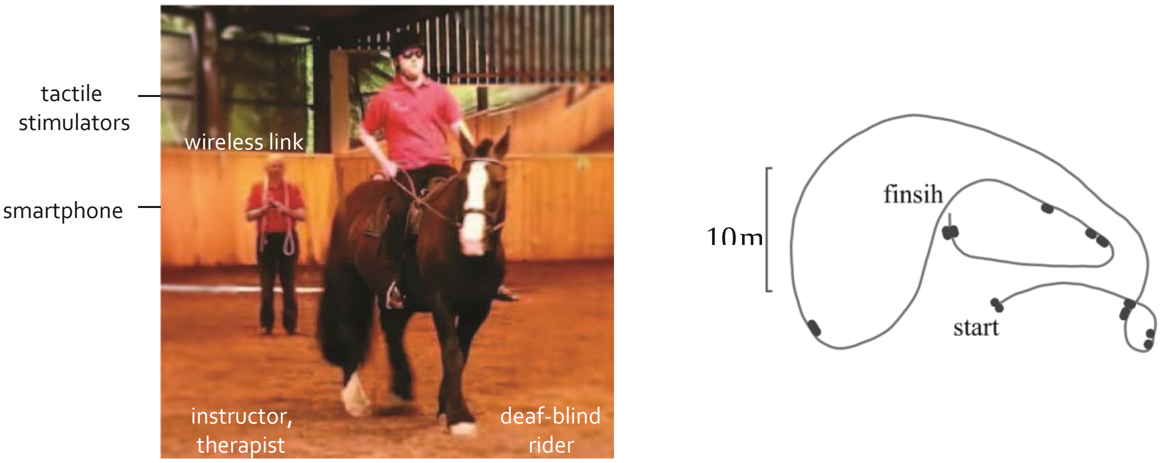
controlled by a riding instructor/therapist with the help of a custom designed Android smartphone application. While a motor is active, the rider pulls the reins in a way to direct the horse in the corresponding direction. The overall proposed concept is illustrated in Fig. 1a.



(a) (b)

Figure 1. *(a) The instructor communicates messages to the rider remotely using the proposed wireless interface. (b) Recorded trajectory of one trial. The markers on the left and right of the trajectory indicate occurrence of a vibrotactile stimulation at left and right arm respectively.*

In collaboration with the RDA (Riding for Disabled Association, UK) we defined a list of basic commands used by the instructors in horse riding with deaf-blind users. The basic commands are: “go”, “stop”, “turn left” and “turn right”. We defined a tactile stimulation combination for each of the vibration motors (left and right upper arms) in accordance to selected basic commands. A short simultaneous vibration (1 s) of both actuators instructs the rider to command the horse forward (command “go” to start the movement). A long simultaneous vibration (2 s) of both actuators stands for “stop”. Vibration on either arm suggests a turn in the respective direction.

The interface was composed of inexpensive, simple and robust components. Two vibration motors (model 307-100, Precision Microdrives, UK) were selected to display haptic instructions to a deaf-blind rider. The motors were powered by a custom-designed control module, which was small enough to be carried in a rider’s pocket. The control module contained a microcontroller and wireless communication electronics. The module connected to a host mobile device via Bluetooth communication protocol. The device was powered by a 3.7 V LiPO rechargeable battery. The proposed interface is low cost: excluding the cost of an Android mobile device, the total cost of the prototype is under £50. An Android OS application has been developed for controlling the interface.

3. A FEASIBILITY STUDY ON DEAF-BLIND RIDING

3.1 Subjects and experimental protocol

We tested our tactile guidance system in real horseback riding in collaboration with the RDA. An autistic deaf-blind rider (male, age 31, completely deaf and blind since childhood) participated in the study where we experimentally evaluated the performance of riding with the proposed tactile interface. He was using the interface for 10 months prior the present study took place. The tests were carried out in a riding arena. The subject wore our tactile interface which was remotely controlled via a smart phone by a professional riding coach. A deaf-blind tactile language interpreter facilitated communication with the rider. An XSens (Enschede, Netherlands) wireless inertial measurements units (IMU) MTw module was attached to the subject’s torso to track their motion (sampling rate 75 Hz) which enabled us to reconstruct their trajectories. Two additional IMUs were attached to the subjects’ upper arms on top of the vibration actuators to detect the occurrence of vibrations and thus synchronize the stimulation and motion capture data. In the riding tests the subject was asked to follow the random sets of commands given by the instructor. All required safety regulations were observed during the tests and permission from the family of the blind-deaf rider was obtained.

3.2 Results

We reconstructed the movement trajectories based on the IMU measurements. Fig. 1b shows one trajectory. The overall feedback from the subject and the therapist was very positive. Their comments indicated that the subject

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has been enjoying the riding sessions with the tactile interface more than the conventional one, as he felt to directly control the horse. The subject felt confident and safe during horse riding with the help of the tactile interface.

However, we report that, some commands to change the direction of riding were not executed. There could be several explanations for this: 1) the subject had issues interpreting the stimuli either due to troubles in perception or 2) lack of attention, 3) the subject pulled the reins accordingly but the horse did not respond to the command. Lack of attention is often associated with attention deficit hyperactivity disorder (ADHD) typical for autistic condition (Burack et al., 1997). The rider however successfully carried out all commands to stop the horse, which is crucial to guarantee safety during horseback riding therapy. A possible explanation for this might be that the stop cue is long (lasts 2 s) which captures the attention of the rider.

4. CONCLUSION

We presented a novel haptic interface which enables deaf-blind people to practice horse riding. The outcome of the tests was very positive. The approach has been well accepted by the rider, his family and the therapist. As reported by his carers, the rider has been looking forward to each weekly riding session. In this paper we analysed the perception and effectiveness of the proposed interface that showed promising results. In the future we plan to take a closer look at the therapeutic effects of the horseback riding with respect to the subject's autism by means of standard assessment techniques used in the field, namely questionnaires. We also plan to improve the ergonomics of the interface and introduce it to a larger number of users.

Acknowledgment: This work is supported by the European Commission under EU-FP7 grants PITN-GA-2012-317488CONTEST, ICT-601003 BALANCE, ICT-2013-10 SYMBITRON and H2020 ICT 644727 COGIMON. We would like to thank Doug Smith from RDA for fruitful discussions and assistance during the tests.

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Eyeblink rate during a virtual shopping game performance for cognitive rehabilitation

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ABSTRACT

We developed a virtual shopping game having four levels using virtual reality technology for realistic cognitive rehabilitation. The objective of this study was to investigate characteristics in eyeblink rate in relation to task difficulty level. Six healthy adults were asked to buy two specific items in level 1, four items in level 2, six items in level 3, and eight items in level 4 at a virtual mall. Shopping items were daily necessaries which were independent of each other. Task performance, subjective assessments, and eye blinks during the game performance were recorded. As a result, the mean numbers of movements buttons used and the mean time required were higher/longer in level 4 than in level 1. The average subjective assessment scores were higher in level 4 than in level 1. Although the transitions of eyeblink rates were individually different, there was no statistical difference between phases, there were some relationships between subjective assessments and eyeblink rates. It suggests that eyeblink rate could be an index that reflects psychological aspects.

1. INTRODUCTION

Virtual reality (VR) technology provides an environment that is similar to everyday life conditions and enables people to evaluate and train cognitive functions in it. In cognitive rehabilitation for brain-damaged patients and people with dementia/mild cognitive impairment (MCI), exercises with an appropriate difficulty level for each individual increase the patient's motivation and produce good results. However, difficulties have been associated with establishing an appropriate task level because of the lack of evidence on its effectiveness (Cicerone et al, 2011). Although various VR techniques have been proposed for cognitive rehabilitation (Knight et al, 2006; Kang et al, 2008), a small number of study including a virtual action planning supermarket considered the task difficulty level and/or related brain activation (Josman et al, 2009; Tarnanas et al, 2012).

We previously developed a Virtual Shopping Test (VST) for a realistic assessment of cognitive function using VR technology (Okahashi et al, 2013). In the present study, the VST was modified to "a virtual shopping game" that had four task difficulty levels. Subjects were asked to buy specific two items, four items, six items, and eight items in a different virtual mall in each task. We focused not only subjective assessments but also eye blinks as a psychophysiological index affected by task difficulty level unconsciously. The objectives of this study were to examine eyeblink rate in relation to the game phase and the task difficulty level. We aimed to gain basic knowledge for the application of the game in medical rehabilitation settings.

2. METHODS

2.1 *A virtual shopping game*

The hardware system included a personal computer, a screen (LCD-MF222FBR-T, I-O DATA). As shown in Figure 1, a visual environment consisted of a Japanese shopping mall was developed with Metasequoia and Open GL. The width of the virtual mall was about five meters and the depth was about one hundred meters. An audio environment of natural sounds associated with a shopping mall was also provided. By clicking on an icon/a shop picture of the screen, users could move forward and turn back in the virtual shopping mall, enter a

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shop and buy an item. Two hint buttons (e.g. List and Bag) were provided to allow users to view some hints during the shopping task. The operation of buttons was recorded automatically, and outputted as a log file after finishing the test.

Figure 1. *Scene of the experiment with a sample screenshot.*

2.1.1 Level setting. We constructed a virtual shopping mall in a virtual space, and set up four different difficulty levels. The virtual shopping mall used in each task had twenty shops and a train station, whereas the arrangement of these shops in the mall differed between tasks. The bottom of the map was the start point, while the top was the goal. Level 1 asked subjects to buy two specific items, level 2 asked them to buy four specific items, level 3 asked them to buy six specific items, and level 4 asked them to buy eight specific items on each shopping list. Subjects had to search the shops that sold specific items and select the target item from six items inside the shop.

2.1.2 Experimental procedure. The subjects were first asked to memorize the specific shopping items while looking at the shopping list with listening to the reading of the contents by a tester. If they failed the first recall test, they were allowed to memorize the items again while looking at the list. Then, they started shopping in the virtual mall when they are ready. They were asked to buy the specific items as quickly and efficiently as possible, while minimizing the use of hints. They were allowed to refer to a blank map set on the left side of the screen at any time during the game.

2.1.3 Outcome variables. The game had eight outcome variables: the number of times subjects used each button on the screen (Bag use, List use, Forward movement, and Reverse movement), the number of items bought correctly (Correct purchases), Total time, Time in the shops, Time on the road, and those could be calculated from the recording data automatically.

2.2 Data Collection

2.2.1 Participants. Six healthy adults (four woman, two men), aged 19-23 years (mean age: 21.3) participated in this study. All participants received written and verbal information about the study and gave written informed consent. The protocol of the study was approved by the Kyoto University Medical Ethic Committee.

2.2.2 psychophysiological index. We recorded the number of times of eye blinks per second during the game performance by using a versatile biological amplifier: AP1000 (Nihonsanteku Co., Osaka, Japan). We adopted an electrooculogram (EOG) detection method to detect eye movements and eye blinks, which was analysed by Bio-Parametar Real Time Analysis System: Map1058 (Nihonsanteku Co., Osaka, Japan).

2.2.3 Procedure. All participants were administered the game in the order of level 1, 2, 3, and 4 with EOG recording and questionnaires concerning subjective assessment after each task. The questionnaire consisted of three questions concerning the degree of task difficulty, the effort required, and psychological load. Each answer was rated on a five-point scale (1-5). Higher scores indicated higher load task.

3. RESULTS

3.1 Behavioral data and subjective assessments

The average game performance was presented in Figure 2-a, b. All subjects accomplished all level tasks. As shown in Figure 2-a, the mean numbers of List use was larger in level 3 than in level 1. The mean numbers of Forward/Reverse movement were larger in level 4 than in level 1. As shown in Figure 2-b, the mean time required to complete the task was longer in level 4 than in level 1. The average time required per shop was the longer in level 2 than in levels 1 and 3. Next, the average subjective assessments was presented in Figure 2-c. All three indexes scores were larger in level 4 than in level 1 ($p<0.01$).

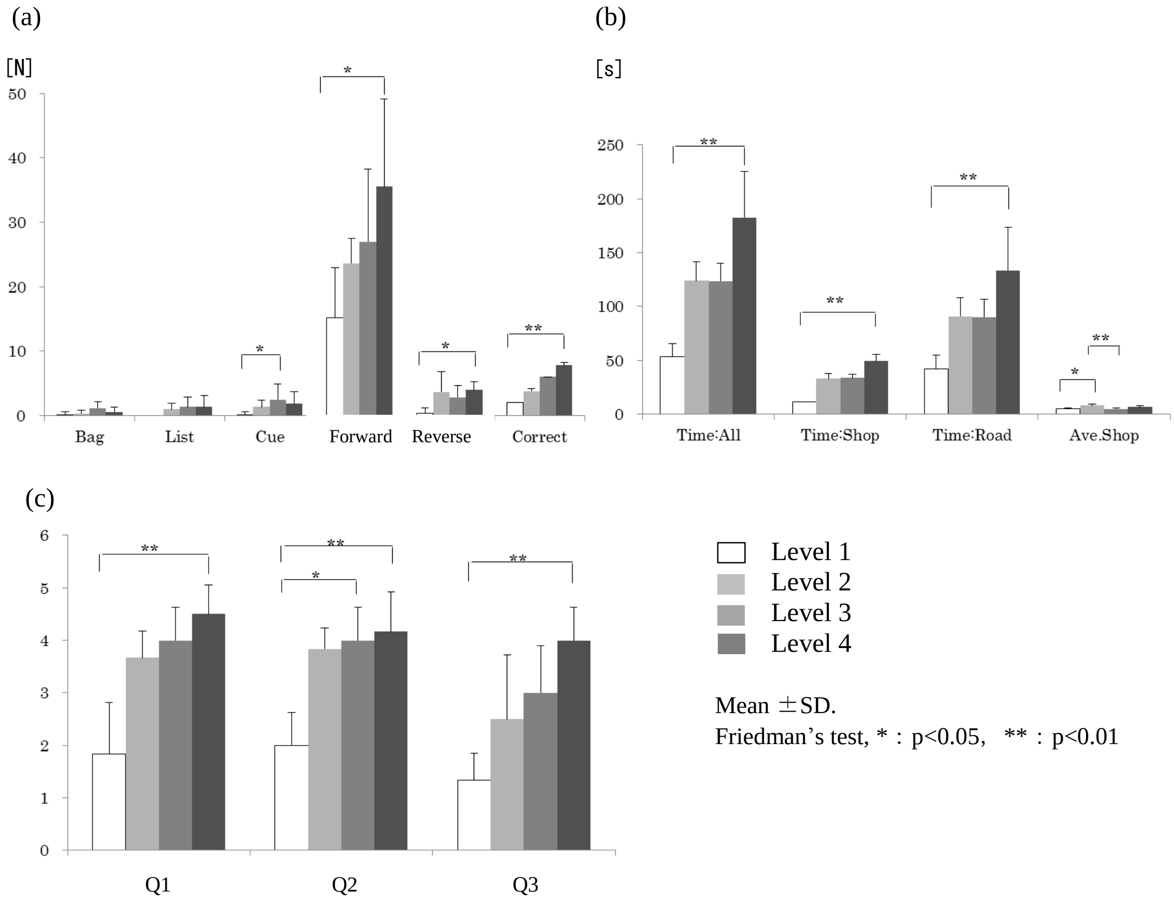

Figure 2. *The average game performance (a, b) and subjective assessments(c) on each task level: (c) Q1: the degree of task difficulty, Q2: the degree of the effort required, and Q3: the degree of psychological load. Higher scores indicated higher load task.*

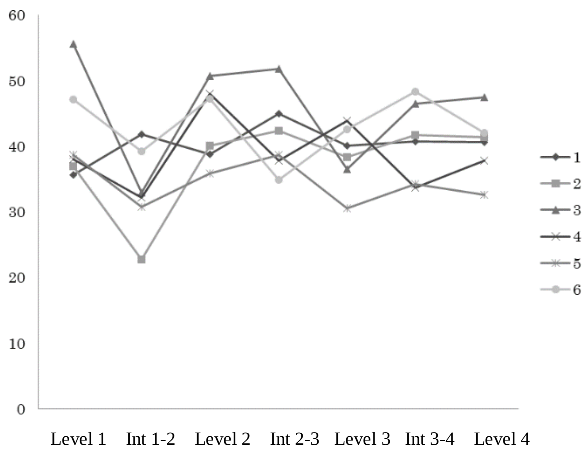

Figure 3. *Eyeblink rate in each phase in each subject.*

3.2 Eyeblink rate

Figure 3 shows eyeblink rate during each level task and each interval between tasks in each subject. The *average* eyeblink rates (number per minute; mean±SD) were 42.0±7.8 in level 1, 33.3±6.7 in the interval between levels 1-2, 43.5±6.0 in level 2, 41.8±6.1 in the interval between levels 2-3, 38.7±4.8 in level 3, 40.9±6.0 in the interval between levels 3-4, 40.3±4.9 in level 4. There was no statistically significant difference between phases.

3.3 Relationship between subjective assessments and eyeblink rate

There were positive relationships between the degree of the effort required in level 1 between eyeblink rates in levels 2 and 4 ($r=0.85$, $p<0.05$). There was positive relationship between the degree of psychological load in level 3 between eyeblink rate in the interval between levels 3-4 ($r=0.84$, $p<0.05$) statistically.

4. DISCUSSION AND CONCLUSIONS

Regarding the game performance and subjective assessment, the mean numbers of Forward/Reverse movement and the mean time required to complete the task tend to be larger/longer in level 4 than in level 1. The average subjective assessments were larger in level 4 than in level 1. It is same tendency with our report using 2-item, 4-item, and 6-item shopping at the 10^{th} ICDVRAT. Then, the eyeblink rates transitions were individually different. There was no statistically significant difference in the mean value between phases. We consider that some personal factors (e.g. characteristic tendencies, experience and taste of TV game) would affect eyeblink rate during virtual shopping game performance. While, there were positive relationships between the degree of the effort required in level 1 between eyeblink rates in levels 2 and 4. There was positive relationship between the degree of psychological load in level 3 between eyeblink rate in the interval between levels 3-4. It suggests that eyeblink rate could be an index that reflects individual psychological aspects on task difficulty, effort required, psychological load, and so on. Blink frequency and duration change significantly over time during a vigilance task, and eye blink information may be an indicator of arousal levels (McIntire et al, 2014). Future research will be needed to analyse the interrelation between blink condition and other indexes such as personal factors and attention in both healthy people and patients with cognitive impairments.

Acknowledgements: We express our appreciation to the subjects who participated in this study. This research was supported by KAKENHI; Grant-in-Aid for Scientific Research (C) (24500643) and KAKENHI; Grant-in-Aid for Young Scientists (B) (16K16461).

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Nicotine-enhanced responding for chocolate rewards in humans

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ABSTRACT

Despite an abundance of evidence illustrating the harmful effects of nicotine use, only a small percentage of users successfully quit (Messer et al., 2008). Moreover, current treatments for nicotine cessation produce only a slight increase in the likelihood of successfully quitting, which emphasizes the need for more effective strategies that facilitate smoking cessation (Hopkins et al., 2001). Several studies suggest that difficulty in controlling nicotine use behaviors results from nicotine's ability to enhance the motivating function of cues associated with obtaining rewards. In order to better understand the reward mechanisms that underlie the risk for becoming dependent, the aim of the current study was to examine nicotine's effects on conditioning, extinction, and reinstatement in humans. Using a novel virtual reality translation of the hallmark conditioned place preference paradigm to investigate the aforementioned objectives, our main findings suggest that nicotine (1) increases the sensitivity of reward properties by enhancing the strength of food-reward conditioning, (2) delays the rate of extinction of conditioned preferences, and (3) increases the reinstatement of previous conditioning.

1. INTRODUCTION

The conditioned place preference (CPP) task is a well-established behavioral paradigm traditionally used in nonhuman research to assess the rewarding or aversive effects of a substance. Using a novel virtual reality translation of the CPP task, the present experiment aimed to understand the behavioral and neuropharmacological mechanisms by which nicotine enhances responding for conditioned rewards in humans.

While most of the toxicity of nicotine use is related to the added components of nicotine-containing products, nicotine's actions as a reinforcer of drug-taking behavior are primarily responsible for the production and maintenance of the dependence. The actions of nicotine as a primary reinforcer are well characterized by self-administration studies (Le Foll & Goldberg, 2009). Nicotine has also been shown to influence associative learning as a result of Pavlovian conditioning where non-pharmacological stimuli paired with nicotine can elicit conditioned responses (DiChiara, 2000; Sayette & Tiffany, 2013). More recently, research has demonstrated that nicotine enhances non-associative responding for other reinforcers by increasing the incentive value of non-nicotine stimuli without requiring a temporal or causal relationship between nicotine and the stimulus or behavior (Perkins & Karelitz, 2013; Buffalari et al., 2014).

There is a paucity of literature regarding the relationship between nicotine and reward-paired stimuli, particularly in humans. Therefore, the present study examined nicotine's ability to increase sensitivity of reward properties in humans by enhancing preference for a virtual environment paired with a chocolate food reward using the CPP task. In addition to investigating nicotine's effects on the acquisition of conditioned behavior, this study aimed to determine whether nicotine slows the rate of extinction for previous conditioning in humans as suggested by several non-human studies (Brenhouse & Andersen, 2008; Elias et al., 2010). Finally, because nicotine has been shown to increase vulnerability to reward-primed reinstatement after extinction (de Wit & Stewart, 1981; Brenhouse & Andersen, 2008), the final aim was to determine whether nicotine will promote the reinstatement of an extinguished CPP.

2. METHOD

2.1 Participants

Ninety-six University of Connecticut undergraduates (avg. age = 19.5 yrs; SD = 1.18; 25 females) were recruited from introductory psychology classes. After exclusions due to ineligibility, Day 1 data from 72 participants (avg. age = 19.3 yrs; SD = 1.12; 16 females), and Day 2 data from 62 participants (avg. age = 19.3 yrs; SD = 1.19; 16 females; Day 1/Day 2: Nicotine/Nicotine, n = 20; Nicotine/Placebo, n = 38; Placebo/Nicotine, n = 22; Placebo/Placebo, n = 32) was used. On average, 10.6 (SD = 8.9) nicotine-containing products were used weekly. Participants were required to abstain from eating and from using nicotine for six hours prior to the experiment. Approval for this study was obtained from the University of Connecticut Institutional Review Board.

2.2 Apparatus

An IBM-compatible computer with a SVGA color monitor was used for testing. Participants navigated through the virtual environments by manipulating a joystick.

2.3 Procedure

This was a two day study with each daily session lasting approximately one hour. On Day 1, food-deprived participants arrived in the morning and consent was obtained. All participants blew into a CoVita Smokerlyzer carbon monoxide sensor to ensure they had not smoked within the last 6 hours (PPM <10). Female participants took a urinalysis pregnancy test that had to be negative. Participants were then randomly selected to receive either a 4mg nicotine lozenge or a similar-tasting placebo. While the lozenge or placebo dissolved, participants completed the Fagerstrom Test for Nicotine Dependence (Fagerstrom, 1989), a standard instrument for assessing the intensity of physical dependence to nicotine where a zero score indicates no dependence, a 1-5 score indicates low to moderate dependence, and anything greater than 5 indicates high dependence.

After completing the surveys, and 15-minutes after administration of the lozenge or placebo to maximize absorption (McEwan et al., 2008), participants were guided through a 90-second practice session in which they were placed in a barren VR room. To encourage exploration throughout the practice session (and in the later experimental sessions), a downward-facing arrow appeared periodically in random locations, and participants were required to locate and collide with it. Three to five M&Ms were dispensed during the practice session, and participants were instructed that throughout the experiment they are to eat the M&Ms as they were dispensed.

After completing the practice session, each participant completed six, 3-minute experimental pairing sessions in a VR environment. The environment consisted of two visually-distinct rooms connected by a neutral hallway (see Fig. 1). In each of the six experimental sessions, participants were confined to one of the two rooms and explored the environment using the joystick. One room was paired with real M&Ms for three sessions, while the opposing room was paired with no food for three sessions. The room paired with M&Ms and the order of the pairing sessions were counterbalanced. One M&M was dispensed periodically into a dish next to the participant during the M&M sessions, and the participant was instructed to eat the M&Ms as they were dispensed. Between 25-30 M&Ms total were dispensed over the course of the experiment. After all six pairing sessions were completed, a 10-minute break was given before the test session.

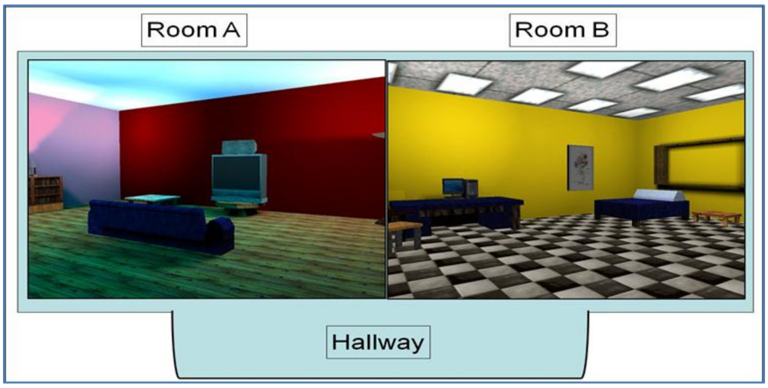

Figure 1. *Both rooms were identical in shape and size, but contained different items, colors and patterns.*

For the test session, participants were placed in the same VR environment and started in the neutral hallway. They had access to both rooms for the entire three-minute session. M&Ms were not dispensed during the test session. After the test, participants were given a survey. Questions asked which of the two rooms they preferred, how much they enjoyed each room on a scale of 0-100 (0 being “not at all”), and how much they enjoyed chocolate on a scale of 0-100 (0 being “not at all”).

On Day 2, participants were again asked to complete the CO test and were then randomly selected to either receive a 4mg nicotine lozenge or the similar-tasting placebo. To test for extinction, the participant underwent three, 3-minute test sessions, as described on Day 1, in which they had unrestricted access to both VR rooms where no M&Ms were given. After the test sessions, participants underwent a 60-second reinstatement session where they received M&Ms in a neutral, novel VR room. After a 10-minute break, participants underwent a final test session to test for possible reinstatement. After the test, participants were given a survey asking the same subjective rating questions as on Day 1. The VR software recorded the amount of time spent in each of the virtual rooms on Day 1 and Day 2.

3. RESULTS

Conditioned place preference scores were calculated as difference scores by subtracting the amount of time spent in the non M&M-paired room from the amount of time spent in the M&M-paired room during the test session, such that any score greater than zero indicated a conditioned place preference for the M&M-paired room. Difference scores in ratings were also calculated this way.

In support of previous findings by our lab (Astur et al., 2014), placebo-treated participants demonstrated a significant CPP by spending significantly more time in the previously-paired M&M room on test day ($t(38) = 1.99$, $p = 0.04$). Nicotine-treated participants, however, did not display a significant CPP in terms of time ($t(33) = 0.67$, $p = 0.51$; Figure 2). In an attempt to determine whether individuals with greater nicotine dependence condition differently than those with lesser or no dependence, we specifically examined the 36 participants who scored greater than zero on the Fagerstrom questionnaire. For individuals with a Fagerstrom score greater than 0, the M&M-paired room was rated as significantly more enjoyable for the nicotine group compared to the placebo group ($F(1, 35) = 4.72$, $p = 0.04$; Fig. 2).

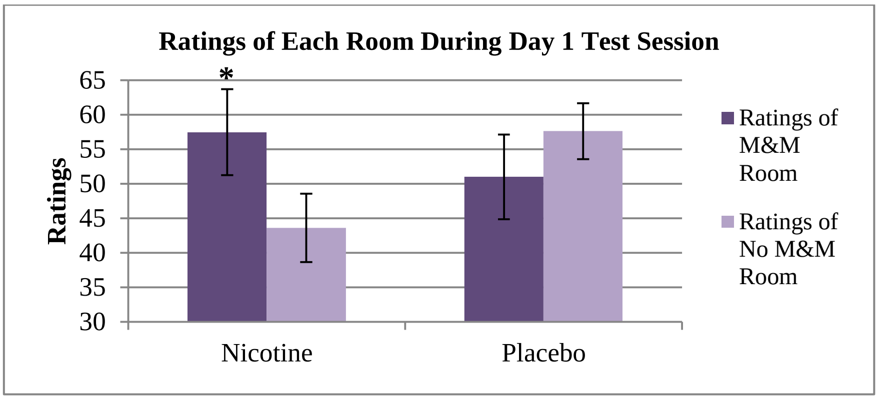

Figure 2. *Day 1 nicotine group rates M&M room more favorably than placebo group when Fagerstrom score greater than zero (F(1, 35) = 4.72, p < 0.05).*

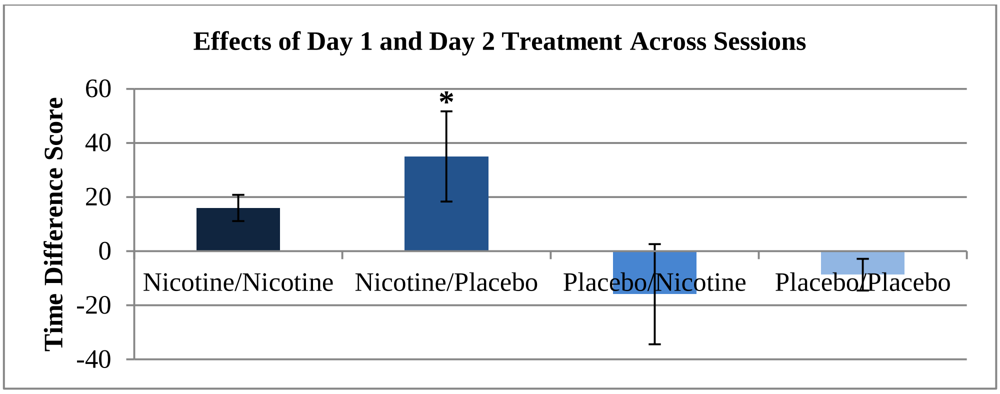

Figure 3. *Effects of Day 1 and Day 2 treatments where nicotine on Day 1 and placebo on Day 2 are most likely to result in a CPP during extinction.*

We next aimed to characterize the effects of nicotine on extinction and reinstatement. When examining extinction, it is worthwhile to analyze those who acquired a CPP on Day 1 since those who did not display a CPP may not have acquired the necessary learned associations needed to readily show extinction. Looking at Day 2 drug effects in nicotine-dependent participants who demonstrated a CPP on Day 1 (Fagerstrom > 0; CPP Difference Score > 0), those who received placebo on Day 2 showed a CPP during the third extinction session by

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spending significantly more time in the M&M-paired room than Day 2 nicotine-treated participants ($F(1, 18) = 5.01$, $p = 0.04$; Fig. 3). What is more, individuals who received nicotine on Day 1 spent significantly more time in the M&M-paired room during the third extinction session than placebo-treated participants ($F(1, 18) = 13.7$, $p = 0.002$). Therefore, nicotine administration on Day 1 and placebo administration on Day 2 appear to be the most influential in determining whether the participant will demonstrate a conditioned place preference during the third extinction session.

Finally, while there were no significant differences between Day 1 treatments in terms of time during the reinstatement session ($F(1, 18) = 3.39$, $p = 0.83$), participants who received nicotine on Day 2 reinstated by a significantly greater change between the amount of time spent in the M&M-paired room during the last extinction session and the reinstatement session compared to placebo-treated participants ($F(1, 18) = 5.87$, $p = 0.03$).

4. CONCLUSIONS

The present experiments were undertaken to characterize the effects of nicotine on conditioned responses in humans using a virtual CPP paradigm. Overall, the present results demonstrate that nicotine does seem to enhance conditioning for a food reward during the virtual CPP task as evidenced by participants who are dependent on nicotine rating the M&M-paired room as significantly more enjoyable when they receive nicotine on Day 1. Nicotine also seems to make individuals more resistant to extinction since those who received nicotine on Day 1 revealed an increased preference for the M&M room in the last extinction session. Lastly, nicotine on Day 2 seems to promote reinstatement of the conditioned behavior following a small amount of M&Ms given in a neutral context after extinction.

The current study provides novel and informative data in understanding the role of nicotine in enhancing CPP preferences in humans using a virtual task. Furthermore, these data provide a foundation for future studies aimed at more thoroughly characterizing the reward mechanisms that underlie risks for maintaining nicotine use, as well as risks for relapse following cessation. Importantly, the current findings of our study will allow for better understanding and interpretation with regard to the mechanisms of nicotine dependence, and hopefully will provide insight into how treatments can be developed and implemented to treat nicotine abuse and dependence.

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Face tracking training in children with severe motor impairment: case report

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ABSTRACT

The article reports an interactive training experience in children with tetraplegia using a face tracking system. Classic assessment scale and specific interactive tasks were used to evaluate and carry out the treatment based on a multimodal approach. The aim of the training was to improve lateral head rotation and oral motor ability with a specific interactive patch connected to the head and face movement. Finally, further trajectory movements and computer control by means of face movement were evaluated. From a descriptive point of view the system proved to be a functional tool to help subjects with severe motor impairment and it empowered the use of their residual functional movements.

1. INTRODUCTION

Face tracking and interaction software provide alternative tools in the treatment of children with severe physical disabilities. They offer a new way to experience through an easy multimodal interface. Tetraplegic children generally depend on caregivers, for them this type of intervention can be a starting point to exert environmental control and therefore improve their quality of life. Interacting with enjoyable activities and making active choices through the new technology access may also prove to be pivotal in the rehabilitation efforts for this population (Sutherland 1968). Head tracking is an old technological topic (Toyama 1998), in the last year many articles have reported different systems using interaction based on visual face tracking technique, especially those that are virtually driven by computer mouse (Rispoli et al. 2014). This specific technology is related to the field of computer access device and assistive technology for people with communicative disabilities (Manresa-Yee et al. 2006; More et al. 2014), but we assume that it can also be aimed to enhance specific activities in a motor training experience.

2. SYSTEM

The system can be decomposed into global head and facial gesture movement control and becomes a feasible solution for different “hand-free” control. The face tracking is based on Free Frame dx9 and provide 66 different virtual marker point usable for interaction on the 2d x-y axes (Figure 1 A). The system requires a PC (we use an Intel core i5) with a commercial webcam equipment and a specific software VVVV (vvvv.org) for the interactive patch. The software was an easy hybrid visual/textual live-programming environment designed to facilitate the handling of large media environments with physical interfaces, real-time motion graphics, audio and video. This instrument easily allowed us to create systematically any patch we needed during the rehabilitative training experience. It has also given us the chance to change any interactive parameter or media feedback in real time and set increasingly challenging goals.

3. CASE REPORT

Here we describe the case of a 4 year old boy with tetraplegia (spinal cord injury transverse C2 -C3 lesion) due to a car-accident trauma. The child showed reduced face and head range of movement, oral motor dyspraxia, no speech ability and low motor initiative. The general assessment showed: suitable cognitive competence, good visual discrimination, no attention and memory deficit, appropriate emotive reaction and good age related education skills.

3.1 Motor Assessment

We selected different scales to assess head and face residual movements. Respectively, the *Clinical Rating Scale for Head Control - CRSHC* (Chavan 2008) to evaluate head postural movement, the *House-Brackmann* (House and Brackmann 1985) and *Sunnybrook Facial Grading Scale* (Ross et al. 1996) to assess face ability.

Table 1. *Head and Face Motor Assessment.*

CRSHC: Grade 0	Supine-Prone-Sitting: No head postural control, require full support.
House-Brackmann:Grade 2	Slight face weakness and asymmetry of smile, complete eyes closure
Sunnybrook Facial Grading Scale: 74	Voluntary movement: 84 Resting symmetry: 5 Synkinesis: 5

The clinical scales selected showed a low sensitivity to measure the child residual motor skill. Therefore, we used the face tracking system also as an assessment tool to evaluate two specific abilities, in pre and post training assessment: lateral head rotation and oral motor movement.

In literature, nose feature has been widely used to track a cursor position (Gorodnichy et al. 2002 and 2004; El-Afifi et al. 2004; Varona et al. 2008) and horizontal head movements are commonly the more reliable tracked trajectory (Sko and Gardner 2009).

We assessed the x-axis range of motion (ROM) using the nose pointing marker n.30, and asked to actively rotate the head on both side. The shift in degree was recorded from starting point 0 with nose in middle position to final position. The assessment reports an asymmetric ROM head rotation mainly on right side: left side ROM 9°, right side ROM 4° (Figure 1B).

The second specific facial gesture detected was the open-close mouth control, action that has been reported as highly reliable in the tracking system accuracy (Jilin and Tao 2007). In our case, we have selected the relation within the two central lips markers, n.61 and n.64 (Figure 1C), to assess the mouth open-close rhythmic control with a specific game: the boy was required to eat a virtual fish in a timely manner, related to the food/target predictable movement (Figure 3 A/B). This game provides basic mouth rhythmic coordination and can be adapted at different speeds. The assessment reported a low mouth tone (often open) and reduced open-close speed and rhythmic control. The child was able to hit 2/20 target match, moving at a 10 sec. speed.

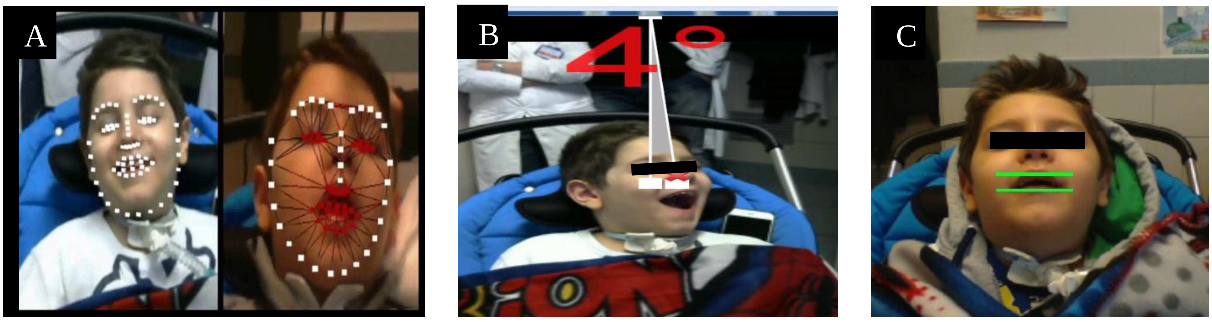

Figure 1. *Face tracking marker system and assessment.*

4. TREATMENT

The child received three daily classic rehabilitative treatments: physical therapy, speech and dysphagic training. Then, we introduced a fourth additional daily training with face tracking: 45 minutes, 5 days a week for 2 months. In our patient reaching active movement was a key point to the treatment, but with a classical training approach we were barely able to activate his stillness and motor initiative. Instead, the interactive face tracking intervention allowed us to more efficiently customize his treatment, by designing personalized patches focused and adapted to engage the user's needs in a growing demanding path.

The interactive tasks aimed to improve active head lateral rotation ROM were: lateral picture slider (Figure 2A), yes/no communication icon selection (Figure 2B), driving a radio commanded car Arduino hacked (Figure 2C) and a classic on line Pc game (i.e. Arcanoid). Lateral head movements activated all these exercises.

The patches aimed to enhance active oral motor synergy with interactive tasks were: video switch triggered by mouth, specific rhythmic “eat fish” game (Figure 3 A/B), different cartoon bubble in communicative context (Figure 3 C), one button on line game played with mouth activation. Open-close mouth movements activated all these exercises.

During the last training session we used more demanding tasks:

- autonomous pc experience using lateral cursor direction linked to nose/head rotation and right mouse click triggered by mouth (Figure 4A).
- training the other residual head motor trajectory (up-down or diagonal) with virtual basket game (Figure 4B) or classic memory game (Figure 4C).

The feedback used during all the training sessions was based on picture or video, with the aim of improving the child’s engagement. All the interactions, except for the common pc games, presented environments of augmented reality, where different graphic visual cues supported the real face webcam view.

Experimenting with the tracking game helped us to understand how we could increase the child motor performance step by step. We re-mapped the trigger feedback, the range excursion or the game speed in real time, therefore calibrating the system to the child performance in a demanding path request.

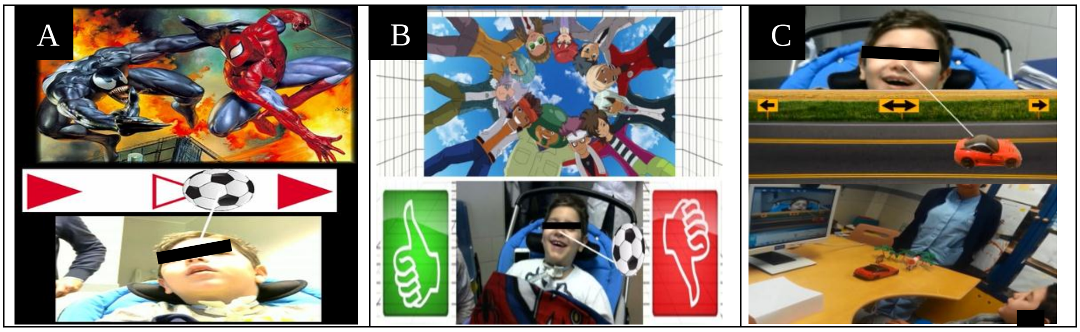

Figure 2. *Lateral head rotation interactive task.*

Figure 3. *Oral motor interactive task.*

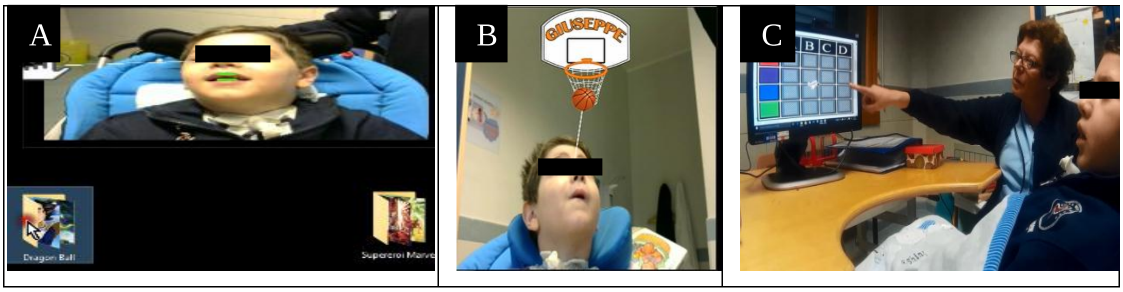

Figure 4. *Autonomous Pc experience and other motor trajectory.*

5. RESULTS

The patient motor training reported an improvement in lateral range of motion and in the mouth open-close control, as assessed with the face tracking system. The final evaluation reported increasing active ROM head rotation on both sides, mainly on right side, and enhanced target hit during the mouth assessment game.

Table 2. *Training results.*

	Pre training	Post training
Lateral head rotation	Left. side Rom 9° - Right side Rom 4°	Left. side Rom 12° , Right side Rom 6°
Oral motor coordination	2/20 goals at 10 sec. target speed.	20/20 goals at 6 sec. target speed.

Global enhancement in selective/synergic face gesture coordination was also observed. The main difficulties our patient encounter during the treatment were related to: 1. speed adaptability during common Pc game, 2. synergic head/mouth movement required during the pc autonomous experience and 3. accuracy in the up/down and diagonal motor trajectory recruitment. The high complex tasks required in the last session were useful to investigate and clarify the child's motor boundary residual skills. The aims of increasing compliance, engagement and general motor initiative were successfully achieved, especially taking into account the patient's stillness and immobility.

6. CONCLUSIONS

The system revealed itself as a functional multimodal user interface that can help subjects with severe motor impairment to empower their residual functional movements. The training also focused on initiative attitude and on introduction to iconic environment aimed at: active media selection, early communication experience, basic Pc control, common game playing and physical playing with a remote car. Therefore, an early approach with interactive technology in engaging experience can be considered a useful tool in a global training approach. Certainly, eye-tracking systems would have been more complete and simple to use for this kind of patients, but it would have led also to a less positive motor performance then the face-tracking system. For a better outcome an integration between the two systems should be planned to empower the visual ability in association with the active head/face skills.

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Process and feedback oriented platform for home-based rehabilitation based on depth sensor technology

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ABSTRACT

In this paper a game-based rehabilitation platform for home usage, supporting stroke and COPD rehabilitation is presented. The main goal is to make rehabilitation more enjoyable and easily accessible for the patients. The platform provides facilities for creation of individualized plans for each patient with a program of game-exercises planned by the patient's caregiver through a web-based planning service. The games are based on specific motion patterns designed in collaboration with rehabilitation specialists. Motion regulations and guidance functions are implemented specifically for each exercise to provide feedback to the user and to ensure proper execution of the desired motion pattern. The caregiver can follow the progression of the rehabilitation and interact with the patient by video conferencing through the web-based service.

1. INTRODUCTION

Following a chronic disease, the primary goal of rehabilitation is to promote a maximal level of function recovery while pushing the bounds of physical, cognitive and emotional impairments (Lange et al, 2011). It is the foundation to enable reintegration into the community and pursued occupation. It has been demonstrated that individuals who perform and have access to multidisciplinary rehabilitation programs show faster functional gains on measures of functional independence and have shorter hospital stays (Hellweg & Johannes, 2008). However, performing therapy exercises without encouragement can cause patients to lose motivation, whereupon the daily process of rehabilitation becomes frustrating and less efficient. Due to increasing medical costs and an increased number of chronic disease patients, every patient's daily exercises cannot be supervised and guided by specialists at all times. Thus, these patients are in need of a functional and reliable home-based rehabilitation system, which can provide cost-effective guidance and encouragement, while supporting remote visual assessment of the performed tasks.

Video games are associated with fun and by developing rehabilitation tools as games the users will perceive motivation associated with playing the games. Although video games have the potential to be used as efficient motivators for performing physical activity, there is a limitation of published research regarding the effectiveness and feasibility of utilizing the motion sensing capabilities of available commercial gaming systems for rehabilitation (Gargin & Pizzi, 2010; Deutsch et al, 2009; Nitz et al, 2010). According to initial case studies, commercial video games can be useful for balance rehabilitation among stroke patients. However, not all commercially available video games are suitable for exercises required for therapy (Nitz et al, 2010; Lange et al, 2010). Furthermore, by extending the gaming platform with video-conferencing and web-based planning and follow-up systems, the rehabilitation can be performed in the patient's home while the physicians, physiotherapists and other related medical staff can monitor and follow up the progression from a distance. Accurate and proper tracking and feedback of motion performance is important in order to achieve maximum effect of the rehabilitation.

In this paper, a work in progress Kinect sensor based platform for home based rehabilitation of COPD and stroke patients is presented. Specific stroke and COPD rehabilitation exercises with different fields of applications are incorporated into the developed games on the platform.

2. MATERIAL AND METHODS

The elaborated home based rehabilitation platform consists of a Kinect 2.0 sensor, a computer with software and a display. The reason for this setup is that the equipment could be easily presented to the user. Provided the user already has a TV screen and a computer, the software and the Kinect sensor can be delivered to the user in a reasonably small box at an affordable cost. Each patient's respective caregiver has access to a web-based system where they can design and plan a rehabilitation program adapted to the specific conditions and needs of the patient. The rehabilitation gaming platform downloads the planned exercises from a server, which enables the user to perform game-based rehabilitation exercises at home, with exercises that are tailored for the individual patient's therapy goals. Motion data from the sensor is collected for each game session and used for motion assessment. The data is also used to provide guidelines and feedback for the user to learn the correct execution of the exercises.

The system displays live video from the Kinect camera on the screen. The user sits or stands up (depending on the exercise) at an appropriate distance from the sensor so that the entire body is visible on the screen. In the game mode, 2D images are placed on the screen in order to activate the user, see figure 1. The user's task is to interact with the objects using different body parts. The placement of the images and the target joints in question determine the type of exercise. Each game is based on a specific pattern of motions designed in collaboration with rehabilitation specialists for COPD and stroke. The games have 10 different levels of difficulty adjusted to the particular exercise in question. There is also a high score list of all the played levels in each game.

Figure 1. *User participating in a boxing game*.

In order to assess if the user performs the exercise correctly, the entire exercise execution is first divided into sub-parts and a start and stop position is defined. Orientation and guideline controls specific for each exercise, with consideration to the defined steps and points, were then implemented in the code to ensure the correct execution. Some of the controls inhibit the progression of the game until the proper motion has been achieved. Other controls provide user guidance through text and voice instructions when the functions are triggered by specific movements.

3. PLATFORM ARCHITECTURE

The rehabilitation platform consists of three systems with integrated components: the caregiver's planning and follow-up system, the patient's gaming system and the web/server system.

1. The planning and follow-up system is a server system accessed through a web-based front-end. Each caregiver (physician, physiotherapist or other related medical staff) has a user account on the system with access to planning tools and progression reports on the associated patients accounts. The system enables the caregiver to design rehabilitation programs for the patients, based on the developed Kinect exercises that can be adjusted for each individual patient's needs and condition. An integrated audiovisual communication system enables the caregiver to interact with the patient through live video and audio. The

caregiver can see what the patient sees on the screen and interact with the patient while performing different tasks in the game.

2. The patient's gaming system is a stand-alone software application running on a computer in the patient's home. The entire game (including menus and settings) is controlled by hand gestures recognized by the Kinect sensor, which avoids the need for additional control devices. The game has two settings, one patient setting and one guest setting. The patient setting is accessed with the username and password of the patient account registered on the server system. When logged in as a patient, the only accessible exercises are those exercises that are planned for the day by the caregiver. The patient setting thus requires Internet access to maintain its connection to the server and to support video-mediated communication with a caregiver. A guest user can access all developed exercises from a menu and adjust the level by choice. Guest users' exercises are not registered.
3. The server system operates as a memory storage of patient specific information that can be transmitted between the patient and the caregiver system. The server stores patient information, such as planned exercises, results of performed exercises uploaded to the server and corresponding assessment data. Once the caregiver has planned an exercise, the information about the daily planned exercises can be obtained by the patient's gaming platform. After execution of the planned exercises, the results are sent back to the server. The high score information of each exercise is however stored locally on the computer hard drive for each specific user.

There are currently 16 developed exercises with different moving patterns and different goal-oriented rehabilitation targets. Each game has 5 levels of difficulty with settings particularly adjusted to the exercises and estimation of patient's capabilities in different conditions. Regulations and control functions have been designed and implemented particularly for each game. These are regulated to prevent cheating, correct movement patterns and for providing guidance to the user. In addition to the rehabilitation exercises, three different assessment tests have been incorporated for COPD patients. Two of the assessment tests are commonly employed questionnaires used for assessment of the current state of the disease in clinical facilities. The third one is specifically implemented for this application as an assessment of the patient's leg muscle strength.

An example of an implemented game is the picking apples exercise. The aim of the game is to pick as many apples as quickly as possible. The apples are placed at a horizontal distance from the shoulders. The apples positioned on the right side are picked with the left hand and apples placed on the left side are picked with the right hand. Text and vocal guidance is provided if the user reaches for the apples with the wrong hand. Guidance is also provided if the user reaches slightly forward to pick the apples instead of reaching directly to the side and the game awaits the user to correct the motion before the apple is removed. Between each picked apple, both hands must be brought back to the center of the body before the next apple appears as a cheating precaution. The distance of the apples position from the shoulders and the number of repetitions increases with the levels and the time frame the user has to pick the apples decreases with the levels. In this exercise the user practice mobility training in shoulder joints and stability training for torso/back. If the subject is standing up while performing the higher levels, the exercise also provides leg strength or balance dependent on the feet distance separation. At the end of the session the fastest picking speed, the average speed and the number of taken apples are presented on the screen.

The games are performed while sitting or standing up depending on the user's physical capabilities and condition. Hence, the difficulty of the games can also be adjusted by alternating the user's performance positions. The simplest case is when the user sits on a chair with the back leaned against the backboard for full support. Next step to increase the difficulty is to sit on a chair with no backboard, and then standing up as a final step. To aid the balance in the standing position a chair or likewise object can be used as support to reduce the risk of falling. To increase the load further, the subject can use elastic rubber bands or hold dumbbells or likewise options in the hands while performing the exercises.

Maintaining a correct posture is important in the execution of several of the developed exercises to obtain full benefit. Position data of the head, neck, shoulders and mid spine was collected from a number of test subjects to observe detection parameters of three types of improper postures: 1) when the posture is hunched forward, 2) when the shoulders are tensed and raised upwards and 3) when the subject is hunched backwards. By utilizing height distance ratios between the tracked joints, threshold values for standing users with tensed shoulders have been found. However, in sitting position the same controls proved unreliable. The horizontal distance between the head and hips/mid spine can be used to indicate hunched positions. However, to optimize the detection of hunched positions a calibration position is necessary to collect user specific data.

4. DISCUSSION & CONCLUSIONS

The home-based rehabilitation system functions as a cross organizational cooperation, where the participation of different care and nursing unit actors is required. All actors involved can access selected information, adjusted for the actor's role in relation to the individual, from a distributed unit. The main focus is the patient's general condition, situation and needs. The purpose of the rehabilitation platform is not to replace the overall recommend rehabilitation activities, but to facilitate and enhance the patient's daily physical or cognitive activity.

The platform is in an early development and evaluation phase. Proper evaluation of patient trials is required in order to fully examine the functionality and effectiveness of the gaming platform. Future work is also intended to expand the client's video-mediated communication system further by introducing a patient group chat option. Furthermore, the possibility of including multi-user exercises in the game, which can be performed at the same location or distributed using video-mediated communication, will be explored. The addition of user friendly interactions and conversations is expected to improve user's acceptance of the system.

Our hypothesis is that the game will provide a more entertaining rehabilitation experience, thereby encourage the user to perform the exercises on a regular basis. The information and feedback about the execution of the exercises could also result in improved movement patterns and thus render the rehabilitation more effective.

The game-based home rehabilitation platform provides COPD and stroke patients with a reasonably priced, easily manageable and entertaining rehabilitation system. The developed system offers improved community of care, encouragement to perform rehabilitation on a regular basis and reduces the need for travel. The motion tracking of the sensor combined with guided feedback helps to improve the execution of the exercise motion pattern and thereby induces efficient rehabilitation training. The stored information of the activity and the results enables the user and other involved parties to follow up on the progression of the rehabilitation. Future work will be done to include communication possibilities not only for health care personnel, but also for friends, relatives and other patients.

Acknowledgements: This project is partly supported by the Centre for Person-Centered Care at Gothenburg University and by VINNOVA, the Swedish Governmental Agency for Innovation Systems.

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Comparison of Wii Balance Board and force platform (baropodometry) for the evaluation of plantar pressures among healthy subjects

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ABSTRACT

This study aimed to compare the use of Wii Balance Board® (Nintendo) with a baropodometer (force platform) to evaluate plantar pressure on healthy individuals. We also analysed the reliability of both platforms and found that, in addition to not being able to validate the data between the two platforms, there not was also a good reliability index in either of the two devices.

1. INTRODUCTION

The human foot functions as a support base during gait (Fortaleza, 2011), in addition to that, it provides support during static stand and flexibility during transfers and correct body support. A correct foot biomechanical alignment is responsible for keeping body posture and a symmetric distribution of plantar pressure (Castro, 2007; Lafond, 2004).

It is important to think about reliable equipment that analyses plantar pressure, particularly because their influence offers an indicative of how the foot function during gait and static posture. This information is also useful to improve the understanding of possible relationship between plantar pressure and posture on the lower limbs (Vianna, 2006; Orlin, 2000).

Higher and unequal distribution of plantar pressures may be the cause of various diseases and deformities, for example pain in the calcaneal region, one commonly seen problem in clinical practice, which can be triggered, due to various reasons such as inflammation, heel spur , fracture, bursitis (Menz, 2006; Zammit, 2010).

The force platform, or baropodometer, permits an analysis on points that have higher pressure, which is considered the gold standard measurement tool to assess the pressure midpoint. However, its high cost limits the possibilities for its use. As an alternative, a Nintendo Wii Balance Board® (WBB) was validated which presented ICC 0.77-0,89 compared to the regular force platform used on evaluations of plantar pressures.

Therefore, the aim of this study was to investigate the degree of reliability of WBB in comparison to the force platform with the purpose of using it as a means of a cheap assessment tool as well as a reliable tool used as the gold standard technique on a public hospital.

2. MATERIALS AND METHODS

The study was composed by six volunteers (male and female) who were workers and students. Inclusion criteria: Independent gait without the use of any assistive device (crutch, walker, cane, etc.); Do not show cognitive impairment. Exclusion criteria: Being pregnant; Having a diagnosis of rheumatoid arthritis; previous history of surgery or trauma n the calcaneal region; Is not undergoing an adjunctive therapy to treat calcaneal region; metabolic or endocrine disorders and have neurological disorders. Participants were informed about the study purpose and after their consent to participate on the study they signed the Informed Consent – IC. The research began with the application of a questionnaire in order to assess whether the individual did fit the eligibility criteria. Subsequently, we used the Mini Mental State Examination (MMSE) to rule out the possibility of individual presenting cognitive impairment and the questionnaire results were evaluated by stabilometric analysis. The evaluation process was done by a previously trained person, other than the research coordinator, in order to avoid bias on the study results. Next, participants walked through the surface analysis plant. The surface support plant was assessed by measurement of plantar pressures in each foot, with the individual in orthostatic position on a Baropodometer. Participants were encouraged to stay as relaxed as possible with bare feet shoulder-width apart and arms along the body, staring at a fixed point, without visual or auditory stimulation and this acquisition was made during 30 seconds. The same measurement was conducted by measuring the individual in orthostatic position on the Wii Balance Board (Nintendo®), which presents an excellent reproducibility compared the force platform with test-retest reliability (ICC = 0.77 - 0.89). The orthostatic test was performed with the same standing position held at the baropodometer, with a position considered comfortable by the volunteer. In addition, they were told to keep their arms at the hip. The parameter considered was the pressure midpoint. To assess the cognitive ability and communication, we used Mini Mental State Examination (MMSE) where the person who applied the questionnaire was previously trained. This test is the most widely used in the world. The MMSE is composed of questions divided into 7 categories, each of them assess specific cognitive domains: temporal orientation (5 points), location, orientation (5 points), 3 word memorization (3 points), attention and calculation (5 points), remember three words (3 points), language (8 points) and visual constructive capacity (1 point). The score varies from 0 to 30 points. The average application time varies from 5 to 10 minutes. The scale has good internal consistency and test-retest reliability (Brucki, 2003).

2.1 Statistical analyses

All statistical analyses were performed using Statistical Package for the social sciences (SPSS Inc. Version 20). The first step was to examine agreement between the two devices by creating a Bland- Altman Plot for the weight discharge for the left and right side. Specifically, this was performed by plotting the differences in weight discharge measures between the two methods against the mean results (Bland and Altman, 1986). A two way, random effects, interclass correlation coefficients (ICC) model was used to assess reliability as well as the within-device test-retest validity and measurement error over the tests. Point estimates of the ICCs were interpreted as follows: excellent (0,75-1,0), modest (0,4-0,74) or poor (0-0,39).

3. RESULTS

The sample consisted of 51 participants, including 17 males (33,3%) and 34 females (66,7%) and the mean age was 34,4 years. The results of weight bearing on the left and the right side, mean difference between baropodometer and WBB and the Interclass correlation coefficient (ICC) are presented on Table 1. The Bland-Altman Plots for the weight discharge for the left and right side are provided in Figures 1 and 2.

Table 1. *Measures during each assessment and reliability.*

	Baropodometer (Mean (SD))	WBB (Mean (SD))	Mean diff (95%CI)	ICC (95%CI)
Pressure (Right Side)	51,51 (±3,24)	51,27 (±5,62)	0,245 (-1,38, 1,87)	0,347 (-0,154, 0,63)
Pressure (Left Side)	48,54 (±3,21)	48,07 (±4,49)	-0,627 (-1,6225, 1,5)	0,402 (0,056, 0,66)

WBB: Wii Balance Board; SD: Standard deviation; CI: Confidence interval; ICC: Intraclass correlation coefficient; Diff: Difference.

4. DISCUSSION

The results of this study show that there was an acceptable reliability rates between the assessments made in the WBB and force platform, corroborating the findings Rebouças et al. in 2013, which compared the use of a force platform with the Biodex Balance System® and found that the comparison between the evaluations of the two platforms also has no statistical significance.

However, the same study, Rebouças et al. say that each platform used by them has its individual reliability, which does not go against described in our study, where we saw that both the force platform as WBB would not have reliability alone, since there is a major discrepancy between analyzes of weight discharges in each leg of a significant number of participants in this research.

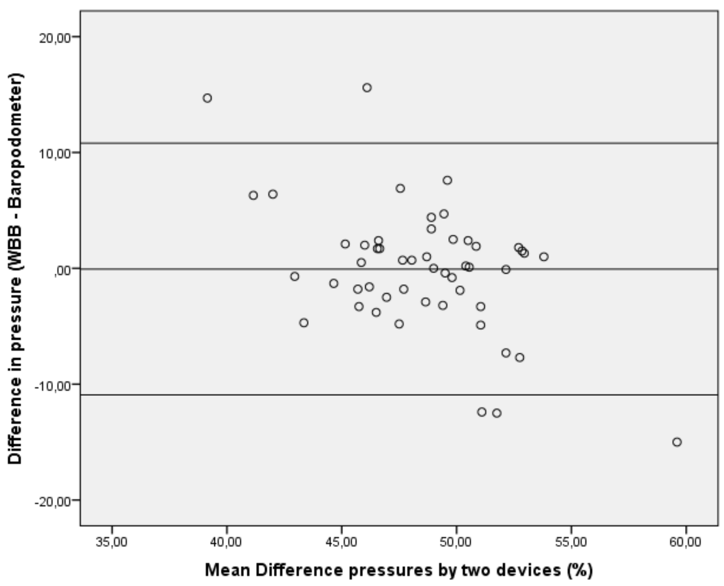

Figure 1. *Bland-Altman plots representing comparisons between the baropodometer and the Wii Balance Board (WBB) for the left side.*

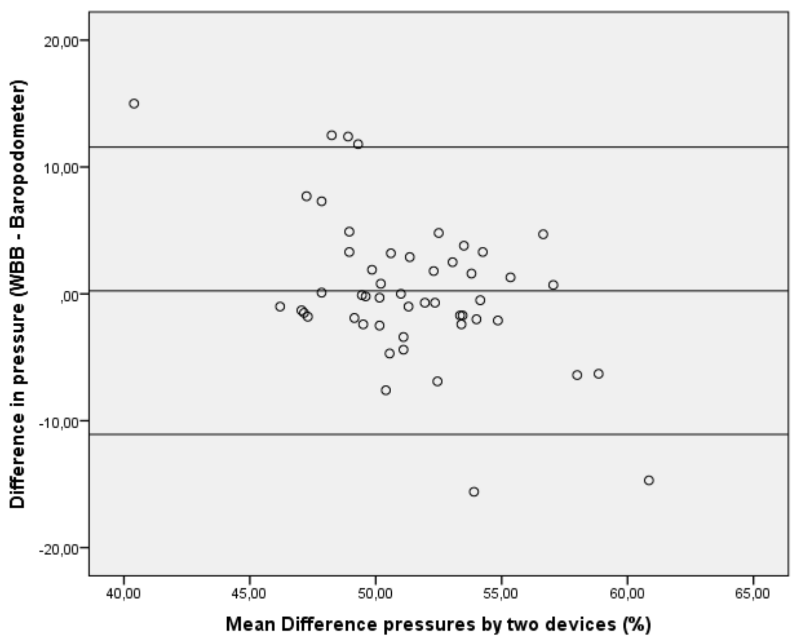

Figure 2. *Bland-Altman plots representing comparisons between the baropodometer and the Wii Balance Board (WBB) for the right side.*

In 2008, Cantalino et al. used a force platform and plantígrafo to compare the results of footprints analysis of several individuals, also coming to the conclusion that there was no agreement between the two methods, a finding similar to ours.

We consider it important to emphasize that only use one of several possibilities for evaluating the force platform, which in addition to evaluating plantar pressure orthostatic allows also evaluate plantar pressure dynamic, static and dynamic balance, and other parameters.

In this study, evaluation was performed only once on each platform, which may have a causal factor for the unreliability found individually on the force platform and WBB, distinguished by the method used Rebouças et al., In that each evaluation was repeated 3 times in each of the two platforms used by them. .

5. CONCLUSIONS

Given all here above, it is concluded that both the WBB and the strength platform have low levels of reliability when used for pressure rating plant. It is suggested that further studies with more participants and more repetitions of the evaluations are carried out to investigate whether the results presented here may have been influenced by the non-repeat method used here.

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©2016 ICDVRAT; ISBN 978-0-7049-1547-3

Reducing impact of stress in patients with psychiatric disorders – a pilot study on the effects of swimming with wild, free dolphins in virtual reality

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ABSTRACT

In this pilot study, a 360^o video VR relaxation program (VRelax) is being developed in order to reduce the impact of stress in patients with depressive, anxiety and psychotic disorders. The relaxing effect of an underwater VR experience with wild, free dolphins will be compared to the effect of an VR experience with natural surroundings such as beach, open fields and dunes and to a 2D experience with video clips of natural surroundings.

1. INTRODUCTION

Stress is defined as demands on individuals that tax or exceed their resources to manage them (Selye 1956). Physical or psychosocial stress elicits physiological, emotional and behavioral responses, which are often adaptive, but also can increase vulnerability to disease. Heightened stress reactivity plays a central role in theories of onset and course of psychiatric disorders, as it has been related to both onset and recurrence of mood, anxiety as well as psychotic disorders (Monroe & Harkness 2005; Phillips *et al.* 2007).

There are two options for altering the impact of stress in daily life: reducing exposure to environmental stress or diminishing personal reactivity to stress (Myin-Germeys & van Os 2007). Personal stress reactivity may be altered by changing negative cognitive schemas or reducing level of arousal, tension and rumination. Changing negative schemas with cognitive behavioral therapy (CBT) requires great effort of therapists and patients. Effect sizes of CBT on symptoms are modest in depressive disorders (Cuijpers *et al.* 2010) and schizophrenia (Jauhar *et al.* 2014). Focusing awareness on the present moment and relaxation by breathing exercises, imagery visualization and progressive muscle relaxation may be more directly targeted to breaking the vicious circle of stress reactivity and psychiatric symptoms.

Relaxation therapy is effective for reducing stress, anxiety and sleeping problems (Manzoni *et al.* 2008), has some effects on level of depressive symptoms (Jorm *et al.* 2008), and has hardly been investigated in patients with psychotic disorders (Vancampfort *et al.* 2013). Virtual Reality offers opportunities to improve relaxation interventions. VR exposure treatments have been developed for various psychological and psychiatric problems, including anxiety and psychosis (Opriş *et al.* 2012; Veling *et al.* 2014). For reducing stress, arousal and tension, exposure should be to a relaxing environment, such as a walk on a beach, scuba diving amidst wild, free dolphins. A combination of visual and auditory stimuli in VR can be used to create an immersive experience that is stronger than the individual's current mental state of distress and anxiety. Recently, a few preliminary VR stress management studies were published, suggesting that this is a promising approach for relaxation and stress recovery, with high potential for further development (Annerstedt *et al.* 2013; Gaggioli *et al.* 2014).

2. METHODS

2.1 Development of Intervention

In this pilot study, we will develop a 360^o video VR relaxation program (VRelax) for reducing impact of stress in patients with depressive, anxiety and psychotic disorders. Feasibility, user-friendliness and immediate effects on subjective and objective stress reactivity will be investigated.

A multidisciplinary team with researchers, clinicians, VR video experts and intended end-users will develop the intervention. Parts of the VRelax program will be developed in sprint cycles of three weeks:

a. Development of first prototype in scrum – all team members
b. Testing of first prototype – two clinicians and two end-users
c. Development of second prototype in scrum – all team members
d. Pilot study in order to investigate feasibility and proof of concept, as preparation for a larger randomized controlled trial (RCT).

2.2 Set-up

The VRelax program will use a Samsung Galaxy S6 smartphone that is connected to a head mounted display, the Samsung Gear VR (HMD, see Figure). When activated, a virtual coach explains the program and gives instructions for use. A VR company provides two 15-minutes 360^{o} videos of relaxing environments (http://viemr.com): an underwater experience with wild, free dolphins (Antonioli & Reveley 2005) and a film in natural surroundings: beach, open fields and dunes (made at the Island of Ameland – NL).

2.3 Pilot study

Pilot study with 30 subjects. Sample size is based on recommendations for a clinical pilot as feasibility and proof of concept study (Hertzog 2008; Thabane *et al.* 2010). Participants will be randomly assigned (10 in each condition) to:

a. virtual dolphin environment,
b. virtual natural landscape environment
c. control condition: 2D video clips of natural surroundings

2.4 Participants

Patients from the clinical departments of UMCG, Department of Psychiatry.

Inclusion criteria:

- Inpatient
- DSM-IV diagnosis of depressive disorder
- Anxiety disorder or psychotic disorder, age >18

Exclusion criteria:

- substance abuse or dependence
- benzodiazepine use > 10 mg / day diazepam equivalent
- Involuntary admission,
- Diagnosis of epilepsy or organic brain damage,
- Insufficient command of Dutch language

2.5 Design

After informed consent, patients are randomized to one of the three conditions. Research assistants will administer baseline measures, including psychiatric symptoms, and subjective and physiological stress measures. Patients will be instructed to use the VRelax tool or watch the video clips twice daily for 15 minutes, once in the morning and once in the evening. The first session will be done in the presence of a researcher and a nurse, for technical assistance and safety. After the first session, subjective and physiological stress measures are repeated, cyber sickness is assessed and user experiences recorded. From the second session onwards, patients will use the VRelax / video clips alone. At day 7, after the last session, a research assistant will repeat the baseline measures, and will conduct a qualitative interview on user experiences.

2.6 Measures

Psychopathology: baseline and after last session: Inventory of Depressive Symptomatology-Self-Rated (Rush *et al.* 2000), Beck Anxiety Inventory (Fydrich *et al.* 1992), Green Paranoid Thoughts Scale (Green *et al.* 2008).

Subjective stress: baseline and after last session: Perceived Stress Scale, a 10-item scale to measure the degree to which situations in the last week have been appraised as stressful (Cohen *et al.* 1983). Before and after each session: ecological momentary assessment single items, assessing perceived stress, anxiety, paranoia, positive and negative affect on a 1-7 ordinal scale (Myin-Germeys *et al.* 2009).

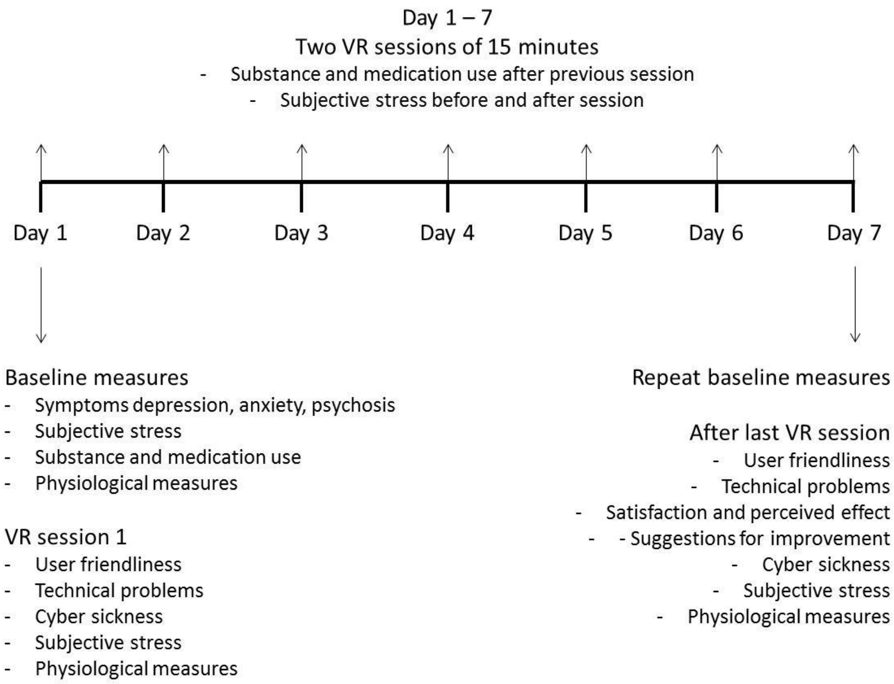
Physiological stress: Heart rate (HR) and skin conductance level (SCL) are recorded on the non-dominant hand in standing position for 5 minutes at baseline before session 1 but after introduction of the VRelax tool, and for 5 minutes after the first and after the last session. Skin conductance level (SCL) is measured using a sensor with two finger electrodes on the middle and ring finger of the same hand with a sampling rate of 10 Hz. Heart rate (HR) is assessed by non-invasive pulse wave measurement using a Nexus 4 with a photo-electric plethysmograph on the index finger.

Medication: use of psychotropic and somatic medication in last 24 hours or since last session, information from patient file.

Substance use: self-rated use of coffee, cigarettes, alcohol, illicit drugs in last 24 hours or since last session.

Cyber sickness: Simulator Sickness Questionnaire (Kennedy *et al.* 1993).

User experiences: qualitative interview.



2.7 Research questions

1. Is it feasible to develop a virtual reality relaxation (Vrelax) tool for patients with psychiatric disorders and to conduct an effect study in a clinical setting?
2. What is the user experience of the VRelax tool?
3. What is the effect of VRelax on subjective and physiological stress measures, compared to the control condition, after one session and after two-daily sessions during seven days?
4. Is there an association between change in stress level after seven days and change in level of psychiatric symptoms?
5. Does the type of virtual environment (with and without dolphins) make a difference in effect on stress measures?

3. STATISTICAL ANALYSES

Data will be analyzed using multilevel repeated-measures random intercept regression models with level of stress (subjective and physiological measures) as dependent variable and VR condition as main predictor. Covariates include medication use and cyber sickness.

4. CONCLUSIONS

This paper is about the first set-up for a pilot study on the effects of 360 degrees virtual reality films in reducing impact of stress in patients with psychiatric disorders. Feasibility, user-friendliness and immediate effects on subjective and objective stress reactivity will be investigated. Dolphin assisted therapy is a popular treatment for children with autism, however without strong scientific evidence, and with dolphins in captivity. An alternative in virtual reality, with wild, free dolphins will be cost effective, dolphin friendly and accessible on demand for every patient.

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Can visual stimulus induce proprioceptive drift in the upper arm using virtual reality?

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ABSTRACT

Sustained isometric contractions (SIC), such as holding an arm stationary in a space, are often used in upper limb rehabilitation exercises, particularly where it is important to protect the joints and tendons or to reduce patient fatigue. However, visual cues within a virtual environment may have an unanticipated effect on the ability to maintain SIC. This study investigated the influence of background motion within a virtual environment on the ability to maintain a fixed position during an upper limb task. It was found that introducing directional movement had a significant differential effect on the ability to maintain SIC.

1. INTRODUCTION

Dynamic arm movements are commonly used in physical therapy to strengthen the arm and increase mobility after stroke, injury or amputation (Atkins & Robert III, 2012; Duncan et al., 2005). In recent years these rehabilitation practices have been coupled with virtual reality due to the tasks being repetitive and intensive, this is sometimes referred to as gamification (Burke et al., 2009). 'Gamification' has shown to be effective making long-term rehabilitation enjoyable and sustainable. Although dynamic movements have shown to be very beneficial for increasing mobility and range, these movements are sometimes too demanding/strenuous for patients suffering from chronic regional pain syndrome (CRPS-1), phantom limb pain (PLP), or post-stroke. (Moseley, 2006). Sustained isometric contractions (SIC) have been shown to provide equivalent strength development but also provide protection to the joints, tendons and muscles while remaining less strenuous for the patient. (Myers, Toonstra, Smith, Padgett, & Uhl, 2015). Similar to dynamic exercises, SIC rehabilitation is generally repetitive and intensive (Burke et al., 2009). When these rehabilitation techniques are placed into a virtual reality setting there may be unintentional repercussions on proprioception. For example, we know the appearance of objects in the virtual reality can influence the time it takes to reach for an object in upper limb tasks, (V. Powell & Powell, 2014) but there is little information about how movement in a virtual environment (VE) may affect upper limb proprioception and movement. Optic flow has been shown to influence the perception of self-motion during walking (W. Powell, Hand, Stevens, & Simmonds, 2006), but little is known about its effects on upper limb tasks. These side-effects of VR design (intentional or unintentional) could be detrimental to rehabilitation. This is especially true for SIC as the duration of the action is much longer than the stages of a dynamic movement. In order to create enjoyable and sustainable virtual rehabilitation for people with diminished upper arm range of movement, it is important to understand how movement in VE can influence the visuomotor system.

Early work into visuomotor controls was pioneered by Aglioti and Bridgeman (Aglioti, DeSouza, & Goodale, 1995; Bridgeman, Kirch, & Sperling, 1981; Goodale & Milner, 1992; Milner & Goodale, 1995). Increasing understanding of how visual input has an effect on how we perceive, plan and execute actions. One of the main conclusions of this early work was the "perception – action model", which suggests that vision and action are split into two different and distinct neural activities.

- *One that sub serves perceptual judgements (planning)*
- *Another that mediates visually controlled action (on-line control)*

This opened many debates as to whether optical stimulus/illusions had an effect on just the planning of an action, the action itself or both or neither. The evidence shows visual stimulus (perceived movement) having an effect on planning and initial acceleration and there is less evidence of it affecting the on-line control of the movement/reach or grasp (Carey, 2001; Franz, 2001; Glover, 2002; Mendoza, Hansen, Glazebrook, Keetch, & Elliott, 2005). Although these results are reinforced by multiple different tests regarding reaching and grasping, these results have been challenged in various ways. Bruno (2001) has stated that tasks that emphasise observer – relative reference frames may contradict the notion that the two systems are completely disassociated with each other. Observer – related reference frames refers to the adjustments made throughout a movement and the feedback loop from different reference points. The objective of this study was to investigate whether visual motion in a virtual environment affects action (SIC) in the upper arm.

2. METHODOLOGY

2.1 Hypothesis

"Movement of the background of a virtual environment will influence the ability to hold a static position during SIC". The independent variables were the direction of motion of the virtual environment background, and the visual appearance of the background environment. The dependent variable was the change in hand position (mm) whilst attempting to maintain SIC.

2.2 Design

An application was created in Unity (5.3.4f1, 64-bit) to track hand movements using a LEAP motion hand tracking device. The application consisted of a digital hand model, a reference object and different backgrounds that would move either left or right. The background moved at a constant rate of acceleration (0.02 m/s^2) through the trial, starting at 0 m/sec and ending at a velocity of 1.25 m/sec. This was the highest speed used in a pilot that did not cause discomfort for the duration of the trial. Participants were told to place their virtual hand inside a reference object and keep their arm and hand as still as possible throughout the trials. Once the application started the reference object disappeared. In order to obscure the primary goal of the task, a secondary task was implemented for the participants to perform. The participants were informed that bubbles would be floating down from the top of the view, terminating on the virtual hand. Their task was to press a button on a controller with their non-dominant hand if they 'felt' the bubble on their physical hand and to keep their hand as still as possible. In reality, the trajectory of the bubbles was actually linked to the hand position, so that if there was any unintentional drift of the hand, the bubble would still intersect with the virtual hand. Each trial lasted 30 seconds with a break of 30 seconds after every two trials in order to limit fatigue (additional breaks were allowed if the participant requested them). During these breaks, the investigator assessed for any signs of discomfort. Overall the participants performed 8 trials consisting of 3 backgrounds and 3 different movement patterns [Table 1]. Hand (X, Y, Z) and bubble (Y) position, button presses (number of times bubble was 'felt') and speed of the background motion were all recorded at 50 Hz to a text file.

Table 1. *List of conditions used: The presentation of the patterns and directions were fully counterbalanced with non-moving control conditions at the start and finish.*

Control (solid grey)	Pattern 1	Pattern 2
No-movement	No-movement	No-movement
N/A	Left	Left
N/A	Right	Right

2.3 Participants

A total of 12 participants were used (9 males, 3 females), with an age ranging from 26-57 (M= 37, SD 9.54). 11 participants were right hand and 1 person was Left handed. Volunteers were obtained from members of staff and students at the University of Portsmouth. The exclusion criteria for this study was: Severe visual impairments, shoulder injuries or restrictions, diminished proprioceptive awareness [e.g. Parkinson's, dyspraxia, etc.], people with visual field epilepsy and those with attention deficit hyperactivity disorder (ADHD), attention deficit disorder (ADD).

2.4 User interface

The user interface consisted of one of three backgrounds; blank [grey], Marbled and Pebbles. These were chosen due to the irregularity of the surface. This meant the background would be able to cycle, seamlessly multiple times across the field of view. These backgrounds did not have any highlighted area that would distract the user.

2.5 Equipment

A Leap Motion Controller was used to track hand movement at 50 frames per second. For this study, it was important to imbue a sense of embodiment onto the arm because the user needs to have a sense of ownership with the arm if they are to be immersed in the VE (Kilteni, Groten, & Slater, 2012). To further this sense of embodiment different skin tones were selectable by the users (3 male and 3 female hands all constituting 3 different skin tones) a fully rigged and animated arm was also used.

In order to fully immerse participants in the virtual environment and occlude the view of their own body, An Oculus Rift DK2 HMD was used, with drivers set to version 1.7 SDK 0.6.0.1, allowing extended monitor functionality. A 1920x1080p resolution with highest output settings was used. The application was created with Unity 5.3.4f1 (64-bit). The HMD output was set in the software as an extended monitor. This allowed the stereoscopic display to be retained without movement tracking. The reason head tracking needed to be disabled was because pitch and yaw have been shown to change the perception of speed in virtual reality (Li, Adelstein, & Ellis, 2009). Open broadcast software was then used to mirror the oculus onto an external screen to allow the investigators to monitor the participant view throughout the study. Participants were seated at a desk, and the height of the chair adjusted such that the arm was in a low fatigue position (45° elevation in the sagittal plane $\theta = 0$) (Wiker, Chaffin, & Langolf, 1990).

3. FINDINGS

The dependent variable was 'overall hand drift' (mm). Overall hand drift relates to the movement in the X-axis from the initial position (Final X position of the hand [30 seconds] minus Initial position [0 seconds]). Overall drift included both magnitude and direction. Quantitative data analysis was carried out using IBM SPSS v22.

A repeated-measures 2-way ANOVA (pattern x direction) demonstrated no significant effect for pattern type [$F_{(1, 11)} = .00$, $p = .99$] on overall hand drift. Since the pattern did not have a significant effect on overall hand drift, the pattern data was collapsed (N=24) for the subsequent analysis and testing.

Table 2. *Mean and standard deviation of the collapsed data showing overall drift (mm) from initial position.*

	Right	**Left**	**No Movement**	**Control**
Mean	0.47	-5.47	-3.52	-4.77
Standard deviation	7.68	9.52	5.4	5.72

Following collapsing the data, a further repeated measures ANOVA was conducted, Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated, ($\chi^2(5) = 9.60$, $p = .0.88$). There was a significant effect of movement type on overall drift ($F_{(3, 69)} = 5.28$, $p < 0.01$).

A Shapiro-Wilk's test ($p > .05$) confirmed that the overall drift results were approximately normally distributed, therefore, posthoc paired T-Tests were performed on the data.

There was a significant difference in the overall drift for Right directional movement (M=0.5, SD=7.7) and control (M= -4.8, SD=5.7) conditions; $t(23) = -3.185$, $p < .01$. Right direction and no movement (M=-3.52, SD=5.4) conditions; $t(23) = -2.59$, $p = 0.016$. Right direction and Left (M= -5.5, SD=9.52) conditions; $t(23) = -2.9$, $p < .01$, However, there was no significant difference in drift between left directional movement and control.

4. DISCUSSION

Overall hand drift generally moved leftward, even in the absence of a moving visual stimulus. As the population of the sample was predominantly right-hand, this leftward trend means their hand was travelling towards medial plane (centreline). This trend could be attributed to fatigue in the arm. This was not unexpected as the arm is horizontally flexed with the forearm pronated (Honan, Jacobson, Tal, & Rempel, 1996). However, presenting a rightward direction to the background motion induced a counteraction to this leftward trend either making the hand more still or reversing the direction of the drift against the leftward trend towards the medial plane. This finding suggests that a background moving laterally to the medial plane might be able to counteract the effects of fatigue in the upper arm. This could be beneficial for rehabilitation programs as this may mean patients could hold fixed positions for longer periods of time. Further research regarding the perception of fatigue in the arm would need to be carried out.

The results supported our hypothesis that background visual motion has an effect on 'action' (sustained isometric contraction), and consistent with the findings by Bruno, Milner and Franz (1995, 2001, 2001). Although the idea that perceived movement in the background can affect action, it conflicts with Bruno's suggestion that reference frames play a significant part in 'action' (Bruno, 2001). With the fixed view, 'observer related reference frames' were minimised and movement was still observed in the hand. It would be hard to justify a unification between the various stages of planning and termination of movement but the finding contradicts Milner and Goodale's (1995) argument to completely separate the two components in the 'perception-action model'.

The pattern of the background did not have a significant effect on overall hand drift. However, this study only compared two patterns, and it is plausible that some differences might have a differential effect. For example, it is known that speed judgements are influenced by the level of contrast (Stone & Thompson, 1992), and further work is needed to establish if other visual factors might affect the influence of background on drift. In addition, further research would need to be conducted on the differences foreground objects and background scenery affect upper limb task and additional data will be required to make a distinction between control and non-moving conditions. This may be useful in manual labour tasks such as conveyer belt manipulation.

Acknowledgements: We would like to thank Jahangir Uddin for software programming and Ruiying Wang for technical support.

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