12th International Conference on
Disability, Virtual Reality and Associated Technologies
in Collaboration with
Interactive Technologies and Games (ITAG)

Proceedings

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Conference Series Editor: Paul Sharkey

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ICDVRAT 2018

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- **Paul Wilson,** University of Hull, UK Peter Wilson, Australian Catholic University, Australia

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11:15 – 11:50	Keynote: NICER User Group
11:50 - 12:20	Session II: End User Involvement in Research
12:30	Lunch
13:30 - 14:15	Session III: Exposure Therapy
14:15 – 15:00	Short Paper Presentations A: Memory and Cognition
15:00	Refreshment Beak
15:15 – 16:00	Short Paper Presentations B: Rehabilitation and Psture
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17:00	Networking, viewing demo stands and poster display
18:00	Drinks Reception

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10:15	Refreshments Break
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10:00	Refreshment Break
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1	Moe the Monkey: A fun way to educate children**, Ikram Asghar, Oche A Egaji, Mark Griffiths and David Hinton**
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46	Why are educational robots not being used in Special Education schools despite proof that they are beneficial for their students? **Maria Jose Galvez Trigo, Penny Standen and Sue Cobb**
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117	Exploring materials and object properties in an interactive tangible system for upper limb rehabilitation, **Fábio Pereira, Sergi Bermúdez i Badia, Rúben Ornelas and Mónica Cameirão**
108	Traumatic brain injury with comorbid post traumatic stress disorder affects performance on virtual reality-based balance tasks, **Marie Onakomaiya, Marcy Pape, Tricia Kwiatkowski, Douglas Brungart and Sarah Kruger**
22	Concurrent virtual rehabilitation of service members post-acquired brain injury – A randomized clinical study, **Grigore Burdea, Kevin Polistico, Namrata Grampurohit, Gregory House, Nam Kim, Michelle Nordstrom, Kiara Buccellato, Justin Murphy and Paul Pasquina**

Welcome to Nottingham – and the people of Nottingham

It falls on me to introduce you to Nottingham and the people that have, and still live here.

Apparently we come from a long line of cave dwellers (we have many caves in, or should I say under, Nottingham). The name itself is derived from a Saxon Chieftain named Snot - seriously. Snot, gave his name to a group of settlements built after 600AD – Snotingham is literally the town of Snot's people[1].

Since then we have been home to a legion of famous inhabitants – from writers including Lord Bryon (Newstead Abbey was his ancestral home and his remains now rest in one of our local towns – Hucknall), D H Lawrence (he spent much of his time in exile from both Nottingham and England – but was born and brought up in Eastwood), and Alan Sillitoe (of Saturday Night and Sunday Morning Fame); Musicians include John Crocker (I thought at first Wikipedia said Joe Cocker, but alas no – he comes from nearby Sheffield), Jake Bugg and the Sleaford Mods (very à la mode); to some interesting religious types – Thomas Cranmer (it didn't end well) and William Booth (of the Sally Army fame).

We have some pretty famous boxers as well – from the past and present (well very recently present). William Bendigo Thompson was born and practiced his art of bare-knuckle boxing in one of our suburbs – Sneinton, and was the last of 21 children[2]. To the present day represented by Carl Froch holding multiple world championships at super-middleweight, including the WBC title twice between 2008 and 2011, the IBF title from 2012 to 2015, and the WBA (Unified) title from 2013 to 2015[3]

But given that we are at heart a science and technology based conference we would like to share the lives of some famous Nottingham researchers. Robert and Erasmus[4] Darwin were botanist, and physician and natural philosopher respectively[5]. Erasmus himself was one of the key thinkers of the Midlands Enlightenment, and slave-trade abolitionist[6]. Another famous Sneinton inhabitant (not a boxer this time), George Green developed the first mathematical theory of electricity and magnetism and his theory formed the foundation for the work of other scientists such as James Clerk Maxwell, William Thomson, and others[7]. What is remarkable is that he was almost entirely self-taught and only ever had one year of formal education. He wasn't entirely happy with his lot as a miller but his windmill still stands in Sneinton, and now serves as a museum to George and his theories[8]. But it can't be all high science and our last Nottingham scientist is Frederick Gibson Garton, the inventor of H.P. Sauce in 1895. Garton called the sauce HP because he had heard that a restaurant in the Houses of Parliament had begun serving it[9]

And finally to someone called Robin Hood (I think a direct ancestor of Errol Flynn? But not he of Men in Tights fame). I'm stretching this a bit but one of our most famous inhabitants is a tree - the gigantic Major Oak stands proud in Sherwood Forest, the legendary hideout of foresaid local and international hero and his merry men.

In fact we are home to a lot of people for a city that's seen as relatively small with a population of 621,000 and 20 million people live within two hours travelling distance of the city.

So the General Conference Chairs, and all the associated committees (Local Organising, Program and Proceedings, ICDVRAT and ITAG Conference Steering, and International Programme) welcome you to Nottingham, and its inhabitants past and present.

Professor David J Brown

[1] *A P Nicholson (9 May 2003).* "Meaning and Origin of the Words. Shire and County"
[2] **https://en.wikipedia.org/wiki/William_Thompson_(boxer) accessed 31/07/18.**
[3] **https://en.wikipedia.org/wiki/Carl_Froch accessed 31/07/18**
[4] **http://www.oxforddnb.com/view/10.1093/ref:odnb/9780198614128.001.0001/odnb-9780198614128-e-7177 accessed 16/08/18**
[5] **https://en.wikipedia.org/wiki/List_of_people_from_Nottingham#Science,_technology_and_scholarship accessed 31/07/18**
[6] Graves, Joseph L. *The Emperor's New Clothes: Biological Theories of Race at the Millennium. p. 57*
[7] **https://en.wikipedia.org/wiki/George_Green_(mathematician) accessed 31/07/18**
[8] **https://www.greensmill.org.uk/about/history-of-the-windmill/ accessed 31/07/18**
[9] **https://en.wikipedia.org/wiki/HP_Sauce#cite_note-guardian1-6 accessed 31/07/18**

Conference Introduction

The 12th International Conference on Disability, Virtual Reality and Associated Technologies (ICDVRAT 2018) 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 22nd 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), Gothenburg, Sweden (2014), and Los Angeles, USA (2016).

ICDVRAT history

The ICDVRAT conference series was initiated by Paul Sharkey, University of Reading UK and started in 1996 as the European Conference on Disability, Virtual Reality and Associated Technologies held in Maidenhead, UK. 27 papers were presented at the 1996 conference representing emerging research in the wide range of applications of VR to health and disability. The second ECDVRAT conference was held in Skövde, Sweden (1998), establishing the biennial conference cycle. The first of the session papers was presented by a user group of pupils with intellectual disabilities from the Shepherd School in Nottingham, UK describing their involvement in the design of a suite of virtual environments developed to help them to practice everyday living skills. In 2000 the conference title changed from 'European' to 'International' reflecting the global reach of contributors and delegates. In 2006, the conference celebrated its 10-year anniversary with a review of the series to date and its first conference collaboration. Held in Esberg, Denmark, the conference was run jointly with the first ArtAbilitation conference celebrating inclusive access to music and art, a partnership that was revisited in 2008 in Maia, Portugal. The largest conference was held in Laval, France in 2012 which had 49 full paper presentations and was the first conference to include short-paper poster presentations. The 20-year anniversary of the conference series was held in Los Angeles, USA (2016), co-chaired by Albert 'Skip' Rizzo, a long-standing contributor to the ICDVRAT community and pioneer in the application of virtual technologies for cognitive assessment and therapy, notably in treatment of PTSD. The 2016 conference was also marked by the retirement of its founder, Paul Sharkey. Paul (co)-chaired 11 conferences held in 10 countries with more than 400 full paper presentations given by delegates from 35 countries. Paul also established a wonderful resource in the full ICDVRAT archive, with all papers 1996-2016 which is available at www.icdvrat.org/archive.htm and the papers from the 2018 conference will be added to this archive. Over this time Paul has brought together a research community of more than 1,000 members with a range of interests in the application of virtual reality and its associated technologies for beneficial use in assessment, treatment and support of individuals with disability, impairment or support needs. We take this opportunity to thank Paul for establishing this strong international research community and showing us the importance of an inclusive approach to technology development. As responsibility for the conference series passes into the hands of its members, we hope that we will continue to develop in the direction of Paul's vision and to support a research field constantly evolving with the emergence of new technology.

ICDVRAT-ITAG 2018

This conference marks the beginning of the next chapter in this conference series evolution, starting with a collaboration between ICDVRAT and ITAG. The ethos of both conferences has always been one of inclusion; providing a forum for discussion and sharing of ideas and innovations between technology developers, clinicians, research scientists and end users. A strong feature of many of the papers presented over the conference series has been the involvement of user stakeholders in the design and evaluation of new technologies and applications providing user assistive technology and applications for learning, rehabilitation, therapy and clinical assessment to a broad range of users and we are delighted that the 2018 conference has a special theme of 'user involvement in research'. In celebration of 20-years since the Nottingham pupils presented at the conference in Skövde, our first Keynote presentation will be given by the NICER user group, including some members who attended and presented at the 1998 conference in Sweden. NICER (Nottingham International Consortium on Educational Research) is a group of people with intellectual disabilities who are interested in research and want to make sure research about intellectual disabilities conducted locally involves people with intellectual disabilities and is informed by their needs and wishes. The group started in 1995 when they took part in a project funded by the European

Lifelong Learning Scheme. Since then they have met regularly to review research proposals that involve people with intellectual disabilities and advise on a wide variety of research projects.

The second invited presentation will be from Skip Rizzo and is entitled: Is Clinical Virtual Reality Ready for the Primetime? Skip has been involved with the conference series almost from the beginning. He is a Professor at the University of Southern California Davis School of Gerontology and Keck School of Medicine Department of Psychiatry and Behavioral Sciences and Director for Medical Virtual Reality Institute for Creative Technologies Research. As a psychologist, he conducts research on the design, development and evaluation of virtual reality systems targeting the areas of clinical assessment, treatment rehabilitation and resilience.

If you want to be able to give dynamic presentations like Prof Skip Rizzo and impress your colleagues with your understanding of their research, you will appreciate the workshop given by Bonnie Connor a Neuropsychologist from California, USA and Ben McPherson, Head of the School of Missimp Nottingham Improv. Many of you will have seen Bonnie presenting her research at previous conferences and we are lucky to have Ben from our very own Nottingham School of Missimp. Ben has been coaching improvisers since 2011 and will help you to develop athletic listening and speaking skills and help you engage more with others by quickly getting on the same page to understand different perspectives.

This year we had a huge number of submissions ranging from literature reviews to reports of design processes to experimental studies. After peer review process, the International Programme Committee selected 24 Full Papers for presentation at the conference, collected into 7 plenary sessions: Serious games for education, End user involvement in research. Exposure Therapy, Stroke/TBI, Cognitive impairment, Technology for rehabilitation, and Healthcare applications. There will be an additional 30 Short Papers presented in three short paper podium presentation sessions: Memory and Cognition, Rehabilitation Posture, and User experience. Short papers will also be presented at a Posters Session. The conference will be held over three days between the 4th and 6th September at the brand new, state-of-the art Teaching and Learning Building on the University Park Campus at the University of Nottingham, UK.

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 Program and Proceeding Committee, with a special thank you to Kofi Appiah, Sheffield Hallam University, UK for 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 2018, we welcome all delegates to the Conference and sincerely hope that delegates find the conference to be of great interest.

Penny, Sue, David and Pedro

Conference Sponsors & Exhibitors

- University of Nottingham
- Nottingham Trent University
- Bright Cloud International
- Interactive Technologies and Games (i-tag)
- International Society for Virtual Rehabilitation (ISVR)
- Mindmaze
- Summit Medical Scientific

Conference Prizes

Bright Cloud - is the 2018 sponsor for Best Full Paper and Best Short Paper awards.
International Society for Virtual Rehabilitation (**ISVR) -** is the 2018 sponsor for Best Student Full Paper and Best Student Short Paper awards.

Keynote Speakers:

Nottingham International Consortium on Educational Research (NICER) - is a group of people with intellectual disabilities who are interested in research and want to make sure research about intellectual disabilities conducted locally involves people with intellectual disabilities and is informed by their needs and wishes.

Albert "Skip" Rizzo – is Director for Medical Virtual Reality Institute for Creative Technologies Research - Professor USC Davis School of Gerontology and USC Keck School of Medicine Department of Psychiatry & Behavioral Sciences. He conducts research on the design, development and evaluation of virtual reality (VR) systems targeting the areas of clinical assessment, treatment rehabilitation and resilience. His work spans the domains of psychological, cognitive and motor functioning in both healthy and clinical populations.

Workshop:

Bonnie Connor, Neuropsychologist, California, USA and **Improvisers** from MissImp, Nottingham's Improv comedy group, lead an hour long participation workshop using improvisation exercises to develop athletic listening and speaking skills, and engage more with others by quickly getting on the same page to understand different perspectives.

Hackathon:

David Brown, Professor in Interactive Systems for Social Inclusion, School of Science & Technology, Nottingham Trent University, UK and **Nigel Newbutt,** Senior Lecturer/Senior Researcher in Digital Education, Faculty of Arts, Creative Industries, and Education (ACE), University of the West of England, UK lead the hackathon event that has been so successful in previous ITAG conferences.

Abstract for keynote presentation I
Working together: Researchers need Users

NICER (Nottingham International Consortium on Educational Research) Nottingham, UK
Oak Field School, Wigman Road, Nottingham NG8 3HW UK
Head Teacher: **David S Stewart** OBE D.Litt.h.c. DL
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Nottingham International Consortium on Educational Research (NICER) is a group of people with intellectual disabilities who are interested in research and want to make sure research about intellectual disabilities conducted locally involves people with intellectual disabilities and is informed by their needs and wishes.

The group started in 1995 when they took part in a project funded by the European Lifelong Learning Scheme

Since then they have met regularly to review research proposals that involve people with intellectual disabilities and advise on research projects that are running. This includes, for example, writing information sheets, designing pilot work, advising on recruitment and dissemination, testing software and advising on accessibility.

NICER members presented at the 1998 ICDVRAT conference in Skövde as well as at several other international conferences including three International Association for the Scientific Study of Intellectual Disabilities (IASSID) meetings in Seattle (2000), Montpelier (2004) and South Africa (2008). The group also teach on masters courses in education at both universities in Nottingham.

To mark their 20 years since they first presented at ICDVRAT, NICER will deliver the first keynote of the conference on their experience of working on research projects and what they have found works best for all involved.

Abstract for keynote presentation II
Is clinical virtual reality ready for primetime?

Albert (Skip) Rizzo, University of Southern California – Institute for Creative Technologies, USA

Professor USC Davis School of Gerontology and USC Keck School of Medicine
Department of Psychiatry & Behavioral Sciences

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Abstract

Since the mid-1990s, a significant scientific literature has evolved regarding the outcomes from the use of what we now refer to as *Clinical Virtual Reality (VR)*. This use of VR simulation technology has produced encouraging results when applied to address cognitive, psychological, motor, and functional impairments across a wide range of clinical health conditions. This presentation addresses the question, "Is Clinical VR Ready for Primetime?" After a brief description of the various forms of VR technology, I will discuss the trajectory of Clinical VR over the last 20 years and summarize the basic assets that VR offers for creating clinical applications. The discussion then addresses the question of readiness in terms of the theoretical basis for Clinical VR assets, the research to date, the pragmatic factors regarding availability, usability, and costs of Clinical VR content/systems, and the ethical issues for the safe use of VR with clinical populations. While there is still much research needed to advance the science in this area, I will make the case that Clinical VR applications will become indispensable tools in the toolbox of healthcare researchers and practitioners and will only grow in relevance and popularity in the near future.

This presentation will be helpful for people who are just now learning about VR and want to know how it can be usefully applied in the pro-social area of healthcare, beyond just gaming and entertainment applications. Experts in either VR or healthcare will get an informed perspective on the state of the field moving into the future.

Bio

Skip Rizzo is a clinical psychologist and Director of Medical VR at the University of Southern California Institute for Creative Technologies. He is also a Research Professor with the USC Dept. of Psychiatry and School of Gerontology. Over the last 22 years, Skip has conducted research on the design, development and evaluation of Virtual Reality systems targeting the areas of clinical assessment, treatment, and rehabilitation across the domains of psychological, cognitive and motor functioning in both healthy and clinical populations. This work has focused on PTSD, TBI, Autism, ADHD, Alzheimer's disease, stroke and other clinical conditions. In spite of the diversity of these clinical R&D areas, the common thread that drives all of his work with digital technologies involves the study of how Virtual Reality simulations can be usefully applied to human healthcare beyond what's possible with traditional 20th Century methods. To view some videos on his work, go to:
https://www.youtube.com/user/albertskiprizzo

Abstract for Workshop
Improvisation exercises to improve your conference participation

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Bonnie Connor, Neuropsychologist, California, USA
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Improvisers, Missimp Nottingham's Improv Comedy Group

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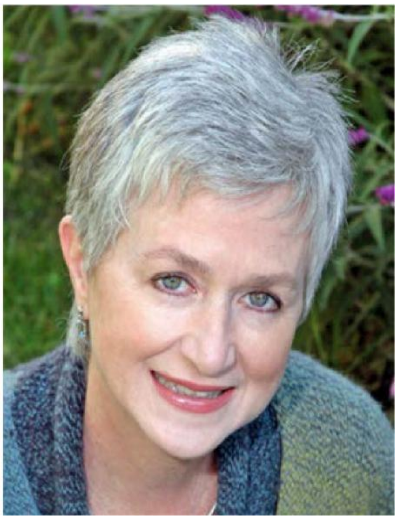

"Want to give dynamic presentations like Prof Skip Rizzo? Want to "wow" your colleagues with your understanding of their research?

In this hour long workshop you will develop skills to get as much as possible out of your conference. You will work together to develop athletic listening and speaking skills, helping you engage more with others by quickly getting on the same page to understand different perspectives.

You will also work on collaborative skills through improvisation exercises to help you engage and incorporate ideas you encounter during the conference. While we can't guarantee you will present like Prof Rizzo, we can guarantee he and the other keynote speakers will participate in the workshop."

Abastract for Hackathon Event
MaTHiSiS – Affective Learning

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David Brown and **Nigel Newbutt** bring the Hackathon event, a very successful tradition of the International Interactive Technologies and Games (ITAG) conference, to ICDVRAT for the first time. This 48hr event takes place during the conference and the final games are presented to the conference delegates on the final day who will vote on the best approach and select the winner of the cash prize.

The hackathon challenge

The challenge is for game design teams to develop games-based learning materials to help people with an intellectual disability or those with autism to learn more effectively. To achieve this, you need to create interactive, technological, engaging learning materials with varying levels of difficulty. The MaTHiSiS system, which will deliver your learning materials, will then adjust the complexity of the materials in response to the learners' emotional state. See MaTHiSiS project website[1] for information on the project that created the tools that have launched this challenge.

Participants can use the 'Learning Game Programming Tool' to develop their game or create external content (e.g. in Python or Unity), and integrate it within the Learning Game Programming Tool as the last part of the Hackathon Activities.

We promote an Agile approach to the Hackathon experience. First start to understand the needs of your target audience – and in this case we hope to pair you up with a person with an intellectual disability, autism, or both to help co-design your solution. Prototyping will then occur after a needs analysis phase based on these co-design experiences. You will then have a chance to re-evaluate your approach working with your co-design partners.

[1] http://mathisis-project.eu/ accessed 19/08/18

ISVR Early Career Researcher Award Winner 2018

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Dr. Sandeep Subramanian is an Assistant Professor at the School of Physical Therapy, School of Health Professions, UT Health San Antonio, San Antonio, Texas, USA. He holds a Bachelors in Physical Therapy from G.S. Medical College and K.E.M Hospital, Mumbai, India. He completed his MSc (2008) and PhD (2013) in Rehabilitation Sciences at the School of Physical and Occupational Therapy, McGill University under the supervision of Dr. Mindy Levin. He was funded by the Physiotherapy Foundation of Canada for his MSc studies and by the Focus on Stroke initiative (by the Canadian Institutes of Health Research, Heart and Stroke Foundation of Canada and the Canadian Stroke Network) and the Faculty of Medicine, McGill University for his PhD studies. He completed a post-doctoral fellowship at the Department of Neurosciences, University of Montreal under the supervision of Drs. Dorothy Barthélemy and Anatol Feldman, which was funded by the Heart and Stroke Foundation of Canada. His research interests include use of virtual reality for upper limb rehabilitation after stroke, non-invasive brain stimulation and outcome measurement. His research articles have been published in journals like Stroke, Neurorehabilitation and Neural Repair, Journal of Neurophysiology, Experimental Brain Research, Journal of NeuroEngineering and Rehabilitation and Restorative Neurology and Neurosciences. He is a member of the editorial board of Restorative Neurology and Neurosciences and is a reviewer for journals including Archives of Physical Medicine and Rehabilitation, Neurorehabilitation and Neural Repair, Journal of Neuroengineering and Rehabilitation, Translational Stroke Research and IEEE Transactions on Neural Systems Rehabilitation Engineering. He is a regular reviewer for the ICDVRAT and ICVR conferences. In addition, he is member of the education sub-committee of the American Society of Neurorehabilitation. He has been invited to deliver presentations on the use of VR in India, USA and UK. His current research focuses on i) understanding the reasons for non-optimal motor improvement in the upper extremity after traumatic and acquired (e.g. Stroke) brain injury and ii) use of interventions including exergaming and transcranial direct current stimulation to optimize motor improvement in the upper extremity. He is currently funded through pilot grants from the Centre for Biomedical Neurosciences and the School of Health Professions at UT Health San Antonio.

ICDVRAT 2018

Papers are listed in Aphabetical Order by First Author

Moe the Monkey: A fun way to educate children

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ABSTRACT

This paper presents the development and usability testing of Evoke, an interactive avatar that can see, hear and respond to children in pitch-altered voice in real-time. The system uses Moe, a stylised monkey, as an interaction point between the teacher and children. Children remained fully engaged, responded more openly, and friendlier to the avatar (Moe), which was controlled by their teacher in a separate room. The user testing showed that the children listened to the character and were eager to ask questions, they grabbed and retained information given by Moe.

1. INTRODUCTION

Augmented Reality (AR) is "a technology that superimposes a computer-generated image on a user's view of the real world, thus providing a composite view" (Walsh, 2011). AR is different from Virtual Reality (VR), as VR offers a computer-generated virtual environment to the users but AR overlays digital information on real-world elements. AR bridges the gap between virtual and the real world, and popularly used in the visual art, commerce, archaeology, military, navigation, architecture, medical and flight training (Chang et al., 2010).

There has been growing research interest in AR application in training/education from academic researchers and industrial professionals due to its significant impact on the world economy. AR is a potentially game-changing technology, its ability to enhance reality with computer-generated sights, sounds and data, transform the way we view and interact with the world. Overall, the revenues from AR market will be over $100 billion by 2020 and the potential education market for AR will be around $300 million. Additionally, the number of AR users will grow at a healthy rate of 35% for the next few years. Currently, over 1000 companies are working in the domain of AR, and it is predicted that over 500 million AR headsets will be sold every year until 2020 (Savage, 2016).

AR can make studying a fun-filled experience. Some recent commercial surveys showed that customers value 33% more AR products than non-AR products. Emerging AR classroom applications include homework mini-lessons, book reviews, yearbooks, world wall, lab safety, deaf and hard of hearing sign language flashcards etc. (Team, 2017).

Many researchers believe that AR can strengthen students' motivation for learning new things and enhance their educational realism-based practices. There has been increasing number of research over the last few years on the adaptability of AR in education, yet the challenges of AR integration with traditional learning methods, development costs, maintenance and resistance to new technology are still there (Lee, 2012). Just like any other discipline, for technology acceptance and retention, empirical studies can act as a roadmap to investigate the potentials of AR implementation into educational settings (Asghar, Cang, & Yu, 2018).

This paper developed a real-time interactive application called Evoke, using emerging technology for an educational environment. The system created an avatar (Moe) that interacts with the audience (children). A motion capture technology was used to control the avatar to mimic teacher's movements. Moe as a teacher in schools, will encourage positive engagement, increase motivation, and increase knowledge retention in the children. Research shows that engaged students tend to be attentive, they show positive emotion and demonstrate more effort as compared to the less engaged student (Fredricks, Blumenfeld, & Paris, 2004). Connell et al. associated student engagement with positive student experience, higher grades and lesser dropouts (Connell, Spencer, & Aber, 1994). Hence, this study aims to investigate the usability and acceptability of newly developed interactive AR application for teaching school children.

This paper contains five sections. Section 2 highlights the literature relevant to this study. Section 3 describes the details of the 'Evoke' prototype. Section 4 summarises the trials and their findings for the validation of the 'Evoke' prototype. Finally, Section 5 presents the conclusion and future work.

2. LITERATURE REVIEW

In recent years there has been rich research carried out in the field of AR assisted teaching at schools and colleges. This section covers recent literature relevant to the current study.

Many researchers have suggested applying AR-based learning into classrooms for subjects including mathematics, astronomy, chemistry, biology etc. through augmented books. However, AR has not seen that much success in the education sector due to insufficient funding from governments, and lack of AR needs awareness in this field (Shelton, 2002). According to Johnson, et.al. “AR has strong potential to provide both powerful contextual, on-site learning experiences and serendipitous exploration and discovery of the connected nature of information in the real world.” (Johnson et al., 2010).

An interesting study used AR in an astronomy class for learning the relationship between the Sun and Earth. The AR system used 3D rendered Sun and Earth shapes. Using a Head-Mounted Display (HMD), the students were able to control the viewing angles of the system elements (Shelton & Hedley, 2004). Another research team tried to teach students about chemistry by using AR through a gripper, a cube, and a booklet. The booklet displayed printed pictures and names of different components; the user reads this information by clicking the gripper button. The user moves the gripper next to a cube, which holds a molecule. Then by rotating the cube, the user determines how and where to connect the element to the molecule (Fjeld & Voegtli, 2002).

Similarly, AR has been used to teach biology. The teachers can use 3D models for displaying human organs to the students in real classrooms. The students can also use HMD to study the biological structures of the human body (Lee, 2012). In an interesting study, Chang et al. developed an AR application called Construct-3D for teaching mathematics and geometry with 3D models. This system allowed students and teachers to share a collaborative virtual space, and they were able to construct geometric shapes through HMD (Chang, Morreale, & Medicherla, 2010).

The AR systems can be especially useful in electrical engineering courses. It allows interactive study and laboratory practices with fellow students and even without the assistance of a teacher (Martín-Gutiérrez et al., 2015). The SMART (System of augmented reality for teaching) an AR-supported educational system has been used to teach students about animal types, and different transportation means through 3D models of animals and transportation. As children love playing games, they got more motivation for learning through AR support, which eventually had a positive impact on their learning experience (Freitas & Campos, 2008).

Chen et al. developed an AR technology called Fishing and Food Chain. The purpose of the game was to teach students different things about fishing, and they enjoyed it (Chen, Ho, & Lin, 2015). Other than these, the AR technologies can be used to teach students about cultural heritage, history of countries, industrial maintenance etc. A comprehensive literature review summarised that approximately 51% studies done so far in the AR field have focused on the K-12 (kindergarten to 12^{th} grade) students, 29% on the university students and 9% on the adult learners. The findings suggest that as usual, young students like to play digital games. Therefore they are the most suitable group for such research (Akçayır & Akçayır, 2017).

The literature shows emerging research interest in AR and its applications in Education. However, the questions like AR usability in education, their efficiency, compatibility with traditional teaching methods etc. still need answering (Shelton & Hedley, 2004). Additionally, previous studies are focused on introducing AR in different educational subjects for adults, not targeted at children. This project aims to bridge this gap by developing a real-time AR interactive learning prototype for children. The system testing involved: delivering lesson through Moe, knowledge retention and usability evaluation of the Evoke prototype from both the children and their teachers.

3. THE EVOKE PROTOTYPE

The project used a wide range of hardware components across two locations (audience and operator rooms) to give the illusion that an animated character is interacting with the audience in real-time. The audience is located in the audience room. The room has the Imagination Station, which enables the audience to view and interact with the Avatar (Moe). The operator/teacher is based in the operator room. The operator room has the Toybox, which enables the teacher to interact with the audience and get video/audio feedback from the audience.

3.1 The Audience Room

The main display cabinet (Imagination Station) is located in the audience room as shown in figure 1. The audience will be young children, who it is hoped will engage with the animated character in a more enthusiastic manner than just being talked to by an adult. The cabinet is a custom-built wooden enclosure with hardware consisting of a Transparent Television Display, CCTV/Video Camera, Display Caster (Input), HDMI Streamer (transmitter), HDMI Converter (if using CCTV camera), Sound Bar and Multi-plug extension. The display caster streams from the operation room PC to the transparent television (Imagination Station), while the television screen displays the output.

Figure 1. *Audience with children looking at Moe*

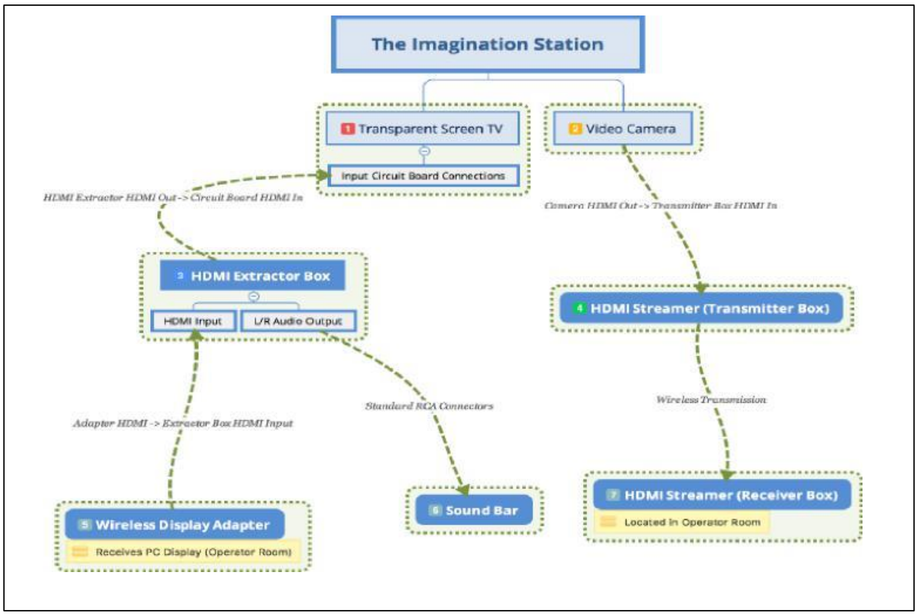

Figure 2. *Imagination station connection diagram*

The camera's video and audio feed are transmitted back to the operator wirelessly through the HD streamer (HDMI Converter (if using CCTV camera)) allowing them to see and hear the audience. The Imagination Station has a separate sound bar that outputs the television sound. Figure 2 shows the connectivity schematic for the various hardware components of the Imagination Station.

3.2 The Operator Room

The operating room can be smaller than the audience room, with enough space to contain all the operator equipment (Toybox) as shown in figure 3. The operator should typically be a teacher who can perform the character of Moe. The hardware composition of the Toybox includes the main PC, Kinect V2 Camera, Kinect for Windows adaptor, HDMI streamer (receiver), two monitors, wired headphones with microphone, two audio extension cables, multi-plug extension, game controller, and a USB mouse. Figure 4 shows the connectivity schematic for the various hardware components of the Toybox. The Kinect 2 camera maps the operator's movements to the on-screen avatar during the performance, and it is connected to the PC via the Kinect for Windows Adapter.

Figure 3. *ToyBox in operator room controlled by the teacher*

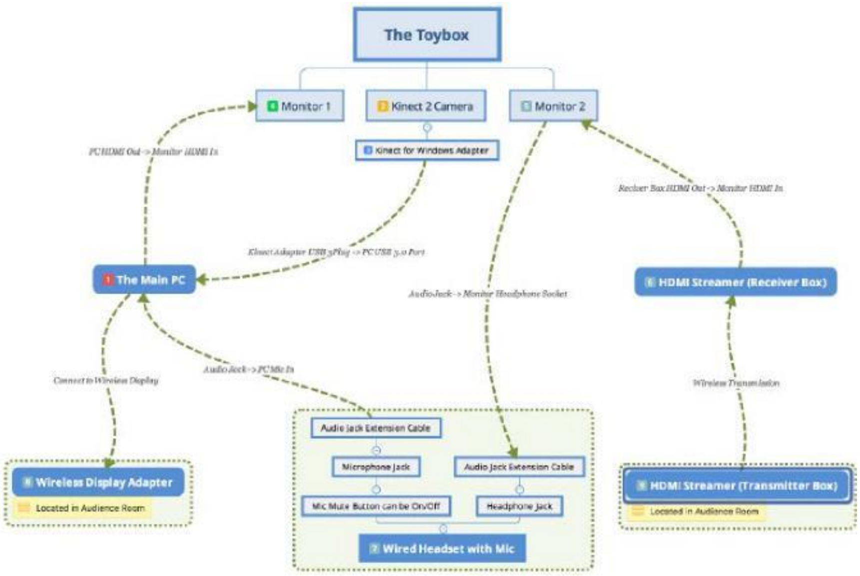

Figure 4. *Toybox connection diagram*

3.3 Spatial and Environmental Considerations
The ToyBox is a large box, and the Kinect 2 camera view of the operator requires that a degree of open space as specified by Microsoft available to allow the operator to perform (Misrosoft, 2018). The Microsoft Wireless Display connection has a limited range. Hence, the Imagination Station and the Toybox should be no more than 23 feet apart with a single wall between them for optimum performance (Microsoft, 2018). It is also advisable to avoid other 5.2GHz functioning wireless device in the area to prevent interference.

3.4 The Moe Character Design (The Program)
The Evoke character runs on Microsoft Windows. The character was developed using Unity (a multi-platform 3D game engine). Once launched, the program shows a standard Unity control panel, which allows the user to change the display resolution of the program, as well as remap the game controller buttons to the various functions allowed in the program (Smile, Frown, Reset Face, Raise Curtain, Lower Curtain, and Start Performance). The main interactive part of the program is the setup screen as shown in figure 5.

There are three selections to make before any performance: -1) select the microphone – choose the microphone to use for voice input, 2) select a character – place a tick next to the character to use, and 3) select voice alteration – choose the type of voice modification required. Once the operator has made these selections, the Start button is enabled. The operator can move into a position where the Kinect camera can 'see' them (the avatar will move from the 'T' pose to mimicking the operator's posture). Once the operator is happy and ready, they can press the Start button on the game controller, which will set up the program with the 'curtains' lowered ready for the audience.

The children can be brought in to the audience room ready for the performance to begin. When the operator is ready, they can use the game controller to raise the curtain, revealing the avatar on a white background, and can talk to / interact with the audience by speaking into the microphone. At this stage, subtle movements are better than moves that are more outrageous. The display on monitor 2 allows the operator to see and hear the audience response.

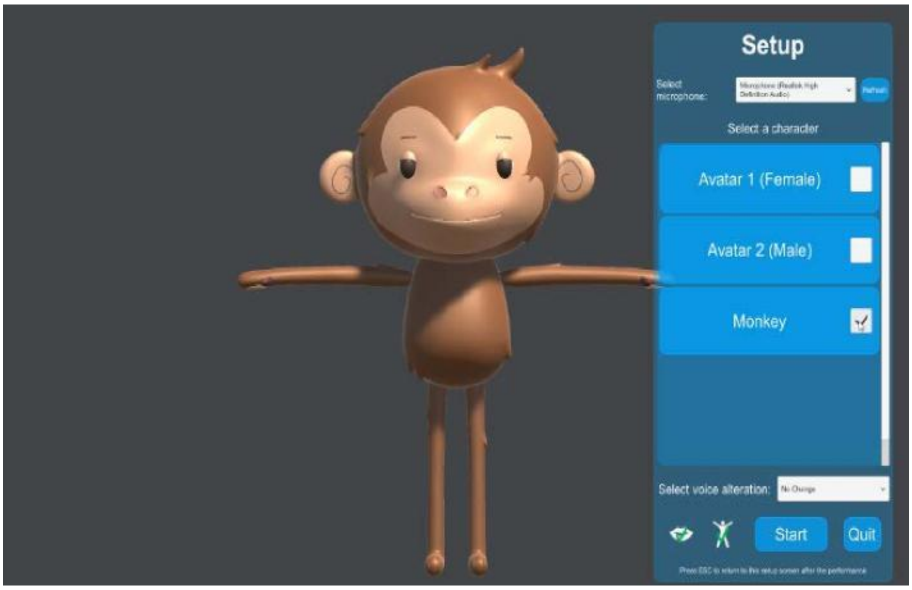

Figure 5. *Program Set-up Functionality*

4. EVOKE TRIALS WITH SCHOOL CHILDREN

By acknowledging the lack of application of AR technologies at schools, this study is initiated to bring AR into mainstream learning. Evoke Education and the Centre of Excellence in Mobile, and Emerging Technologies (CEMET) developed a real-time interactive learning application for children. Working collaboratively, CEMET has supported the development of the 'Evoke' prototype. The product has been tested with children and teachers in Wales to ensure the developers address all aspect of the user experience. This section summarises the testing and trials done with children and their teachers to test the efficacy of the Evoke prototype.

4.1 Interface and Function Evaluation
The 'Evoke' prototype is developed using an agile methodology which uses "iterative work sequences that are commonly known as sprints". Therefore two children were informally involved at different points to test the

interface and functionality of the Evoke prototype. Based on their responses the Evoke prototype was modified, and functions were revised many times before the final testing.

4.2 System Usability and Stability Evaluation

The pilot studies after every sprint helped to finalise the Evoke prototype based on the actual requirements of the children. In total 13 school children participated in the final testing and trials for the Evoke prototype in a classroom setting. The children ages ranged from 7 to 10 years. The children and teachers were asked to complete short questionnaires after each testing activity. The children were helped to complete their questionnaires by a member of the test team. The final testing phase included the following steps:

- Setting up a classroom with children
- Setting up an operator room with a teacher controlling the movements of Moe
- Delivering a lesson through Moe
- Asking a series of questions to children through Moe to test their knowledge retention
- Asking the children and teacher to fill out the questionnaires to investigate the usability of the Evoke prototype.

The questions for the questionnaires were formulated based on the ease of use, attractiveness, learnability, and efficiency of Evoke prototype. For the knowledge retention part, the teacher (through Moe) asked questions of the children about different aspects of the story narrated to them, while test team members noted their answers. For the usability questions, the test team members distributed paper-based questionnaires among the children and teacher. They spoke to the children and helped them to complete these questionnaires.

4.3 Questions and Answers

The children and teachers were given the opportunity to give answers to some questions at the end of the testing and trials. Short and simple questionnaires were used for this purpose. The summarised information arising from the questions asked to children and teachers is presented in table 1 and table 2 respectively. The children liked Moe as a teacher and were interested to know more about the character and listen to what Moe had to say to them. They were very excited to answer the questions that were asked by Moe and liked the shape, facial features and the body movements of Moe. They were also eager to carry out the task set out by Moe. These tasks increased the children's enthusiasm and interactivity with Moe. According (Ibrahim and Al-Shara, 2007) the core focus of educators is to increase students' retention and achievement. Previous research around this area indicates that increasing interactions during teaching sessions between students and their teachers can increase their achievement and knowledge retention (Fredricks et al., 2004). Hence, an increase in engagement between the students, and their teachers can increase their knowledge retention.

Table 1. *Summary of questionnaires data from the children*

Q. No.	Questions	Feedback on Experiences	Suggestions
Q1	What do you think about the Moe	The children liked the character and were interested to know more about the character.	
Q2	Do you understand what Moe is saying?	The children understood what Moe was saying	The Welsh language could be clearer
Q3	What did you learn from Moe?	The children came to know Moe's favourite food Television show and that Moe can swim	Moe to make some more body movements.
Q4	What do you like about Moe?	The children liked Moe's action, facial expressions. They were happy with the way it is.	They want to see more actions from Moe
Q5	What do you want to ask Moe?	The children asked Moe few questions, and Moe replied happily.	
Q6	Are you scared of Moe?	The children were not scared of Moe. Moe was nice and a very good talker.	
Q7	Would you be interested if Moe teaches you at School?	Yes, from every one	

Table 2. *Summary of questionnaires data from the teacher*

Q. No	Questions	Feedback on Experiences	Suggestions
Q 1	How did you find connecting to the Evoke Toybox?	It was easy to connect. Teachers in the school know IT equipment well, it would not be aproblem for them to connect such equipment	Training is required to familiarise with this
Q2	Can you start the program and raise the curtain?	Yes, the teacher was happy to raise the curtain and start the program. She was happy to operate the hand-held controller.	Teachers need a lot of practice to get used to the multitasking while using this equipment.
Q 3	Can you see the children in the Audience room?	Yes, the teacher can see the children.	
Q 4	How easy to speak using the wired Microphone	Getting used to theprocess required.	More and more patience will help
Q5	Are you able see and hear the audience	Yes, can hear the children. There is no time lag	
Q6	How did you find narrating the story by making different body movements?	It's fine in narrating the story	Needs to prepare for the lesson beforehand
Q7	How was the knowledge retention of the children?	It's really good; children remembered everything	Teachers could use this for different school projects

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Table 1 summarises the children responses to the usability questionnaires about Moe as their teacher. Table 2 summarises the teacher's usability questionnaires. According to both tables, the children and teachers were happy with the testing activities and performance of the 'Evoke' prototype. Furthermore, the interaction with Moe was easy and fun filled. The teachers also agreed that the children were able to grab useful information from Moe during their lessons. As most of the modern day teachers are IT literate, therefore having them integrate this current prototype to their teaching would not pose many challenges. However, more teacher training will be required. The results of this testing are promising, as it highlights the need for this technology in education. However, additional test and more details test for generalising these result are required.

5. CONCLUSION AND FUTURE WORK

This paper focused on the development and testing of an AR-based Evoke prototype for enhancing child education. The system development followed agile methodology by involving children during development. The results of initial testing and trials revealed that children like Moe as their teacher and showed considerable interest in learning from Moe. Interestingly the testing results further highlight that the children were able to grab and retain useful information from Moe.

For results generalisation, the research team is conducting further trials with schoolchildren and their teachers to see the potential of Moe being their classroom teacher. Another interesting future research direction would be to have a controlled group and involve different age groups of children to test Evoke usability. The psychological research on the benefit of using AR within education and its effect on knowledge retention would be a great contribution to the body of knowledge. Evoke Education and CEMET are also keen on researching the possible usage of the 'Evoke' prototype for professionals to interview vulnerable children as children can speak more openly to Avatar as compared to humans. The future research will aim at answering the following research hypotheses:

H1: The use of AR has a positive impact in educating children than in non-traditional manners.

H2: The children feel more connected to an AR character than a real teacher or professional child counsellor.
H3: Through the use of AR character, the children grab and absorb more information than traditional teaching methods.

H4: The children want to retain AR character as their teacher.

Testing of these hypotheses through further trials will present a clear picture of the true potentials of using Moe (AR systems) in educational settings and their impact on children learning. Additionally, the range of movement of Moe are limited, and the system has a degree of set-up overhead as well. Further work is required to overcome these limitations.

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Objective assessment of the effect of blue-tinted spectacles on L-dopa induced dyskinesia in a patient with Parkinson's disease.

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ABSTRACT

Introduction

Parkinson's disease (PD) is the second most common progressive neurodegenerative condition worldwide. In spite of extensive research, L-dopa remains the most effective drug option for controlling motor symptoms of PD. Notably, its use is complicated by the development of levodopa-induced dyskinesia (LID).

We describe the case of a 76-year-old man with an 11-year history of PD who developed LID 7 years ago. A reduction in dopaminergic therapy improved his dyskinesia and the patient reported motor and psychological improvements with the use of blue-tinted spectacles. In our experience, this is not uncommon in PD, despite limited evidence in the literature.

Methods

In order to assess for these changes, the patient's dyskinesia was scored using the Unified Dyskinesia Rating Scale [UDysRS] whilst wearing the adjusted, personal blue-glasses, unadjusted coloured-lenses (light-blue, green, red and yellow), with no spectacles and with a blue plastic sheet. Assessment started 25 minutes after the last dose of L-dopa and lasted approximately 1 h. Videos were independently rated by 3 authors (FB, FL, RS) and the mean dyskinesia score calculated for each condition, with lower figures indicating less LID. No statistical analysis was performed due to the small sample data.

Results

Our data suggests there were no clinically appreciable differences in dyskinesia associated with the utilisation of coloured lenses in our patient at the time of filming.

Conclusions

Whilst our results did not show appreciable differences in any condition tested at the time, the incidence of PD patients with no previous knowledge on the subject who report motor benefits from seeing through blue-filters/lenses warrants the repetition of this assessment on a larger scale.

1. INTRODUCTION

Parkinson's disease (PD) is the second most common progressive neurodegenerative condition worldwide. In spite of extensive research, L-dopa remains the most effective drug option for controlling motor symptoms of PD. Notably, its use is complicated by the development of levodopa-induced dyskinesia (LID). The reported incidence of LID in PD varies considerably across studies. In randomised trials, this was found in approximately 40% of patients after 5 years of treatment (Rascol *et al.*, 2000; Ahlskog and Muenter, 2001).

Different types of dyskinesia have been described, the most common occurring after L-dopa administration when dopaminergic stimulation is maximal, hence the name "on-period" or "peak-dose" dyskinesia (Guridi, González-Redondo and Obeso, 2012). Typically, this involves generalised choreic movements of the upper half of the body worsened by stress and activity. Instead, "off-period dystonia" manifests when L-dopa concentration in the body is particularly low, such as in early mornings, with foot or leg pain (Manson, Stirpe and Schrag, 2012). The third type of LID, diphasic dyskinesia, occurs at onset and offset of L-dopa action. Management strategies for "on-dyskinesia" include: dose fractionation, using longer acting oral dopaminergic agents, such as extended release ropinirole, infusion therapies, such as subcutaneous apomorphine or intrajejunal levodopa-carbidopa gel, and deep brain stimulation (DBS). Amantadine, an N-methyl-d-aspartate (NMDA)-type glutamate receptor antagonist can also be added as an anti-dyskinetic agent (Guridi, González-Redondo and Obeso, 2012). Non-pharmacological strategies such as physiotherapy and physical activity have also shown to carry some benefits (Heumann *et al.*, 2014).

Tinted, light-filtering lenses have been widely publicised and contentiously linked with beneficial effects for children with visual stress (Evans and Allen, 2016). Some evidence also suggests red-tinted lenses can improve photophobia in acquired cone disorders and achromatopsia (Young, Krefmanm and Fishman, 1982; Schornack, Brown and Siemsen, 2007). In our experience at the rehabilitation clinic, PD patients often report some subjective and motor benefits from seeing through blue coloured plastic sheets. So far, however, the usefulness of blue filters/lenses in PD has not been well-documented in the literature. This case seeks to explore whether coloured spectacles, notably blue ones, improve LID in one of our patients.

2. CASE PRESENTATION

A 76-year-old man, ex-lorry driver with PD and a 7-year history of dyskinesia reports consistent psychological and motor benefits from the use of blue-tinted spectacles. He presented to our neurology clinic 11 years ago with a long-standing tremor in the left-hand which had started to involve the right and with gait abnormalities (stopping and festination). He had rigidity in the limbs and bradykinesia, worse on the left, a negative retropulsion test and no ocular or cerebellar abnormalities; a diagnosis of PD was made.

Initially, his PD was treated with a combination of dopamine agonist (ropinirole 3 mg t.d.s.) and L-dopa (cobeneldopa 62.5mg t.d.s.). By 2010, his co-beneldopa dose had increased to 125mg five times daily and on-dyskinesia with compulsive behaviours had been noticed (excessive smoking and wood carving). His co-beneldopa was switched to carbidopa/levodopa/entacapone 18.75mg/75mg/200mg (Stalevo 75) five times a day leading to better LID control. In 2013 he reported head and neck pain which was thought to be due todystonia. At present, this affects him for less than 30 mins/day. His PD is otherwise well controlled and there is no evidence of hallucinations, sleeping difficulties or compulsive behaviour. Current therapy includes ropinirole XL 8 mg o.d. and Stalevo 50 (carbidopa/ levodopa/entacapone 12.5mg/50mg/200mg) 1 tablet every 2-hours (max 7 per day). He scored 29/30 on Montreal Cognitive assessment about 2 years ago. He has been under weight (last recorded BMI 16.3, 2014) and hypotensive (80/56 mmHg) for years, with no orthostatic hypotension, dizziness or previous falls records. Our patient suffered from a stroke 18 years ago from which he has made a good recovery and has resulted in a mild left-sided weakness. He has chronic back pain (surgery in 2012) and constipation for which he takes an osmotic laxative (lactulose). He is a socially active individual who lives at home alone, enjoys his independence and relies on his sister for support when needed.

In 2011, shortly after having experienced the first LID symptoms, our patient tried to see through blue coloured plastics in our clinic and described some motor and psychological benefits. Since then, he has been using a pair of reading spectacles with lenses of the same shade of blue, daily for prolonged periods of times, consistently reporting enhanced motor control and “calming” effects (see Patient’s perspective).

In order to evaluate these improvements, our patient was filmed whilst performing the four tasks of the Unified Dyskinesia Rating Scale (UDysRS) under different conditions (see Table 1). The UDysRS is a rating tool designed to test the severity of on-dyskinesia and off-dystonia by means of filmed tasks (objective part) and questionnaires (historical part) (Goetz, Nutt and Stebbins, 2008). On the test-day, the patient had taken his medication 25 mins prior to starting the filmed assessment which lasted approximately 1 hour. The patient was assessed under seven different conditions: 1) with the patient’s own blue glasses (see Supplementary file-Video 1, 2); 2) with no glasses (see Supplementary file-Video 1, 2); with non-adjusted coloured glasses, in the order: 3) light-blue, 4) yellow, 5) red and 6) green spectacles (videos not shown). Finally, a blue plastic sheet of the same shade of his spectacles (7) was used (videos not shown). Independently, three authors (FB, FL, RS) scored the videos and the average values for each were plotted (see Table 1). Following the assessment, the patient completed the questionnaire based on his perception of on-dyskinesia and off-dystonia (historical part of UdysRS). Moreover, he was asked to provide some comments on the perceived effects of the different lenses (data not shown).

3. OUTCOME AND FOLLOW UP

Despite the small differences in averages across the various conditions (see Table 1), according to the authors of this study, there were no clinically appreciable differences in motor performances under any condition. Given the small sample size, no statistical analysis were performed.

According to the historical part of the UdysRS, the patient’s on-dyskinesia was present most of the time when he was awake (14h/day) with a relative sub-score of 28/44. Instead, off-dystonia was present for less than 30 minutes per day with a sub-score of 8/16. Globally, his historical score for LID was 36/60.

At the time of the test, the patient suggested his blue lenses and the blue-plastic sheet were of help, but the non-adjusted light-blue lenses did not provide any improvement (data not shown). According to the raters, he exhibited mainly choreic movements, consistent with on-dyskinesia while performing the tasks (data not shown).

Since the test day, our patient has been seen once by RS in his clinic for a follow-up appointment. On another occasion, he provided his perspectives on the usefulness of his own blue-tinted glasses (see Patient’s perspective).

Table 1. *Sums of impairment and disability due to the patient's dyskinesia during the four tasks, under seven different conditions using the UDysRS.*

	Blue – glasses (owns)	No glasses	Light-blue glasses	Green glasses	Red glasses	Yellow glasses	Blue sheet
Rater 1 (FB)	21	19	23	23	25	28	22
Rater 2 (FL)	19	14	20	23	23	24	15
Rater 3 (RS)	22	23	22	24	21	22	17
Average	**20.67/40**	**18.67/40**	**21.67/40**	**23.33/40**	**23.00/40**	**24.67/40**	**18.00/40**

3.1 Patient's perspective

"I first tried the blue glasses after a nurse made me try to see through a blue plastic sheet, here in the clinic. She told me it might help me. I found it worked, so I had a pair of glasses made with the lenses of the same blue colour".

"I had tried no other colours before".

"I keep the glasses on for most of the day except when I am walking because I'm scared I might break them as I did in the past, [however] when I used them for walking I felt steadier".

"I use them for most of the tasks inside the house especially while playing dominos, using my tablet or playing cards. Outside the house, I use them also when in restaurants".

"I feel they improve the tremor as well as the dyskinesia".

"When I wear them I feel better and more in control. I feel like its magic when I put them on and I would recommend these to anyone".

"It is challenging to walk on the streets with these glasses at night on as they are very dark [therefore] I use another pair of reading glasses with normal lenses at night".

4. DISCUSSION

To our knowledge, this is the first case attempting to objectively assess the usefulness of tinted lenses in ameliorating dyskinesia in a PD patient. A literature review was performed on Pubmed and Medline to look for similar studies, but no pertinent results were found. On the internet, a video allegedly records the effects of a pair of blue tinted glasses on the motor abilities of a PD patient (RevZonenet, 2012).

At present only anecdotal evidence (Neurotalk, 2012; Wikiversity, 2016), including our own experience at the rehabilitation clinic, substantiates these claims. Previously, an unpublished, single-blinded study based on similar evidence, tested whether coloured-lenses were able to immediately improve bradykinesia, as opposed to dyskinesia, in PD (Lanstrum and Runyan, 2005). In this case Timed Up and Go (TUG) and Nine Hole Peg tests were used to assess the degree of changes in 24 PD patients (Hoehn and Yahr stage 2-4) tested, each, under four randomised conditions: with no glasses, with blue, grey, and yellow tinted spectacles (Lanstrum and Runyan, 2005). No significant differences in performances were found (Lanstrum and Runyan, 2005).

Outside of PD, the main rationale behind the utilisation of blue-filters is their ability to protect the retinal photoreceptors from the damaging effects of chronic blue-light exposure (Leung, Li and Kee, 2017). How these filtering properties may improve dyskinesia and/or PD symptoms in a minority of patients is difficult to say. It is tempting to suggest, coloured filters may reduce some of the visual difficulties experienced in PD, indirectly improving motor functioning. In fact, visual dysfunctions are reported by almost 80% of PD patients and include colour sensitivity defects (Archibald *et al.*, 2011; Urwyler *et al.*, 2014; Weil *et al.*, 2016). Impairment in colour vision may correlate with motor dysfunction in Parkinson's (Oh *et al.*, 2011). Interestingly, the blue-cone pathway, which encodes for the stimuli which would be partially filtered by such spectacles, could be particularly affected in PD (Haug *et al.*, 1995; Birch *et al.*, 1998); even though more recent evidence suggests this is not the case (Silva *et al.*, 2005; Oh *et al.*, 2011). Moreover, no association between disease duration or PD symptoms severity and chromatic defects was found (Silva *et al*., 2005). In our case, an improvement in LID wearing any coloured glasses tested was not clinically detectable (see Supplementary file-Video 1, 2). Of note, our patient's colour sensitivities along the visual axes were not tested.

Despite our attempt to objectively assess the patient's responses, many were the limitations of the assessment. The patient was serially tested under different conditions for about 1 h, after 25 minutes from his last L-dopa dose. During filming, the L-dopa concentration in his body would have changed, likely affecting his LID. As he was performing the tasks for the first time, he got accustomed to them, which facilitated their repetition. Moreover, the same "cookie jar chart" was used for task A), enhancing the patient's recall of sentences previously used. Another bias to our experiments were the patient's opinions about the effectiveness of his blue lenses. In addition to that, analysis of the videos using the UdysRS proved to be challenging; although this scale is validated for intra and inter-rater variability, its application requires expertise (Goetz *et al*., 2009).This, together with the lack of experience of some raters (FB), may have contributed to the variations in the scores (see Table 1).

A plastic sheet of the same colour of the patient's glasses was used to assess if the perceived improvements were associated with a particular shade of blue. Interestingly, the performance under this condition was the best overall (see Table 1) and was associated with positive subjective experience (data not shown). However, an assistant held the blue-sheet on the patient's eyes while he performed some tasks, hence these results are poorly standardisable.

5. CONCLUSIONS

Visual dysfunctions in Parkinson's disease include impairments in colour vision and reduced contrast sensitivity and blue-coloured lenses have been anecdotally associated with improved PD symptoms and dyskinesia. This report did not detect appreciable differences in dyskinesia associated with the utilisation of coloured lenses in our patient at the time of filming.

Given the incidence of PD patients with no previous knowledge on the subject reporting some benefits from seeing through blue-filters/lenses, the repetition of this assessment on a larger scale may yield more representative results.

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F.R.A.M.E. (Facial Remote Activity Monitoring Eyewear) - Real-time patient feedback through facial expression utilising wearable technology.

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ABSTRACT

Facial paralysis is a weakness of the facial muscles, typically on one side of the face, affecting facial appearance and the ability to communicate emotions. Advancements in sensor technology have enabled the development of a wearable device to measure a patient's facial muscle activity. Electrical activity of selected facial muscles can be measured in real-time with biocompatible, discrete and reusable electrodes within the device. Therapists will also remotely monitor the progress of their patients and adjust exercise routines as required, helping patients to practice their rehabilitative exercises regularly and correctly and contributing to their speed of recovery for symmetric facial expressions.

1. INTRODUCTION

Facial paralysis results in weakness of the facial muscles, typically on one side of the face affecting the facial function, appearance and communication of emotions. Patients experience issues with speech, swallowing and blinking, plus significant psychological difficulties (Morales et al., 2013) such as anxiety and depression.

Bell's Palsy represents 60% of facial palsy cases, resulting in up to 25,640 new cases in the UK annually. Approximately 8,000 of these new Bell's Palsy cases are left with a permanent disability each year – estimated figures of over 100,000 people living in the UK with permanent facial problems are likely to significantly underestimate the problem (Julian and Partridge,2008). There are approximately 152,000 new strokes per year in the UK, with an estimated 26,000 of these patients suffering from residual facial problems after their stroke. The benefits for these patients of 45 minutes daily physiotherapy in the early recovery period are well known but the costs to the NHS of providing such therapy are large (around £2,600 per patient or £62,400,000 per year).

Studies show that following facial paralysis rehabilitative exercises speeds recovery improving the end result. Patients usually have limited awareness of the abnormal movements their faces display so, without feedback their facial function may worsen, developing permanently abnormal movements.

Currently, patients are shown their exercises in clinics and are expected to practice alone at home using only a mirror for feedback. Many patients dislike having to work with their own reflection as it reminds them of their condition and many get discouraged.

Wearable technology that provides real-time facial muscle information to patients and therapists promises a significant improvement in the rehabilitation of facial paralysis (Nicastri et al., 2013), allowing wearers to practice their exercises discreetly and correctly whilst completing other daily activities.

1.1 Patient Benefit

A key aspect of the system currently being developed is to provide valuable feedback to a patient as they go through the rehabilitation process while suffering from Bell's palsy. Sensory feedback to show the patient their progress is vital in ensuring that patients continue to do their daily exercises, it is not always evident that improvements are being made using traditional techniques such as using mirrors and standard stretching and massage exercises.

During everyday activities, patients are unaware of how their facial muscles are behaving and often become discouraged from social activities such as meeting friends/colleagues for drinks or returning to work. The implementation an indistinctive pair of glasses to alert the patient to this synkinesis will allow the patient to return to these everyday activities and will alert the patient should they need to make any corrections in their facial expression. Continued use of the glasses would help the patient retrain their muscles in order to return asymmetry to the patient facial expressions over time.

The system has the potential to be of benefit to patients by:

1. Providing useful advice and guidance on exercises and massage routines;
2. Providing daily prompts to remind the patient to do their exercises;
3. Improve the patients resting asymmetry using the EMG mask daily;
4. Adjust facial expressions to retrain muscles to overcome Synkinesis;
5. Provide valuable feedback on progress and demonstrate improvement;
6. Reducing the need for patients to visit hospitals and clinics for rehabilitation;
7. Provide free advice and guidance for patients via the mobile application stores on IOS and Android.

1.2 Clinical need

Approximately 8,000 new Bell's palsy cases are left with a permanent disability each year within the UK. These patients are referred to specialists within the NHS for further treatment and rehabilitation; the patients will receive an initial assessment where they will be provided with information sheets and guidance on exercises and massages that they can perform at home on a daily basis. It is important that patients receive the correct advice and guidance as soon as possible after the onset of Bell's palsy, as the patient begins to recover movement within the muscles the advice changes and the number and nature of the exercises change.

The system has the potential to benefit therapists by:

1. Providing an online, remote monitoring solution to view patient progress;
2. Provide home based EMG exercises therefore freeing up therapists within the clinic;
3. Provide valuable data in the analysis and diagnosis of Bell's palsy.

2. PROJECT AIM

The project aims to develop a wearable glasses based solution that will be used in the patient's home without the constant supervision of a therapist. The patient will interact with the device and receive instruction and advice through their own personal mobile device providing regular prompts to help the patient keep up with their daily routines (Van der Weegen, S. et al., 2013). Therapists will be able to support the patient and provide them with custom exercise routines administered remotely via an online portal to provide the best treatment possible with minimal impact on both the patients and therapists time.

Figure 1. *The FRAME system overview*

2.1 Treatment Paths

Patients suffering from Bell's palsy will fall within one of three different categories during their treatment; Flaccid paralysis (weak muscles and a drooped face), Paretic (weak facial muscles, incomplete recovery), and Synkinetic (tight, overactive muscles with loss of movement due to uncoordinated muscle activation). During their recovery they will slowly progress from Flaccid to either Paresis or Synkinesis, each of these conditions require different exercises and advice to ensure that the patient receives the best treatment possible.

2.1.1 Flaccid condition

When a patient is in the flaccid their muscles are paralysed, they cannot move the muscles and have no control over their facial expressions. During this stage, the patient is provided with a number or stretch and massage exercises to help them maintain passive mobility of the facial soft tissue whilst recover is awaited. They are also given advice on how to care for their eyes. At this stage, the patient will be provided with advice and exercises within a mobile application.

2.1.2 Paretic condition

Incomplete recovery of the facial nerve following injury results in variable levels of weakness. The degree of facial droop at rest depends on the age of the patient. However, during active expressions there will be reduced muscle activity on the affected side. This is commonly assessed using a 6-point grading scale, from zero muscle activity to maximal activity.

2.1.3 Synkinetic condition

In approximately 30% of individuals, the facial muscles will be permanently tensed, with the muscle tone at rest sometimes higher than on the unaffected side. This causes fatigue within the muscle that may cause the patient pain or discomfort. Once a patient has started to achieve some movement within their facial muscles, they may experience a condition called Synkinesis, this is where the nerve pathways for their facial muscles become crossed and the patient will experience involuntary movements during every day facial expressions. For example when the patient smiles their eye will close or narrow involuntarily. During this stage, the patient will be provided with expression monitoring eyewear pair of glasses designed to monitor the asymmetry of their facial features, the glasses will provide biofeedback in the form of a vibration or light that will alert the patient to the involuntary movement (Giggins OM, et al., 2013). The patient will then be able to 'retrain' their facial muscles to prevent the involuntary movement and to reduce the effect of the Synkinesis.

3. INITIAL RESEARCH

Initial system design concepts were based on research into the required locations for EMG sensors. The first prototype was a glasses design with 4 EMG sensors around a glass style frame. This demonstrated the ability to detect a subset of expressions such as winking, blinking, frowning, smiling. However, two issues led to a decision to alter the development. Firstly, difficulties in simultaneously measuring both smile activity and eye closure reliably using EMG sensors in a glasses format led to a reconsideration of the sensor type for the glasses. Secondly, the fact that the majority of patients have difficulty in achieving control over their baseline muscle tone meant that an intermediate sensor array would be needed to manage their initial problem of raised muscle tone.

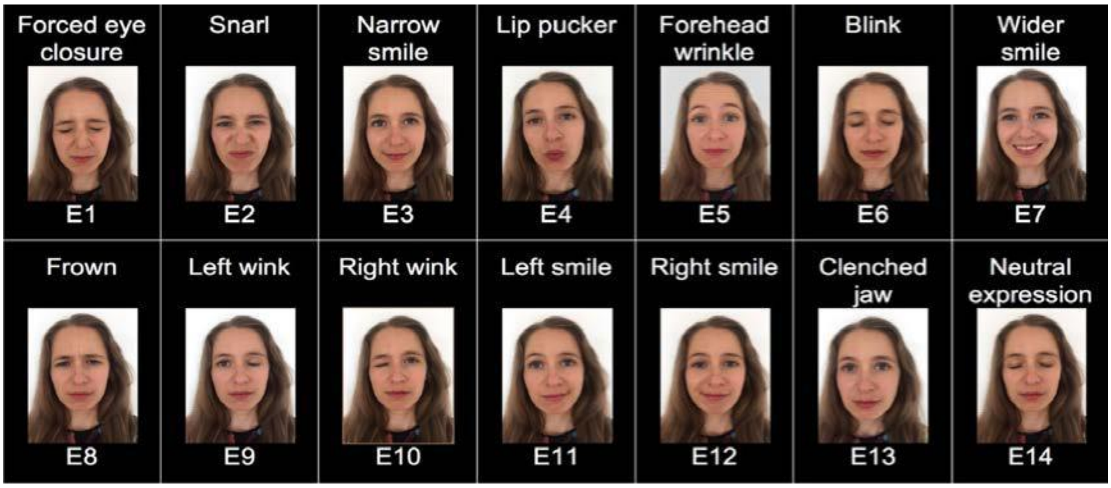

Figure 2. *Final expressions selected for analysis and coding. Snarl, forehead wrinkle, frown, narrow smile and wide smile have been selected to represent disgust, surprise, anger and happiness respectively*

A goggle-styled system has been prototyped and tested with six EMG sensors during different facial expressions. It became evident at this time that the EMG sensor mountings would need to be flexible to allow the sensors to rotate and adjust to the changing morphology of the patients face as they performed the facial expressions. It also became evident that an additional two sensors would be required to detect movement within the lower part of the patients face and would need to be located on the patient's cheeks.

Further research was undertaken to identify which muscles would need to be monitored in order to identify a number of emotions and facial poses as required during exercises conducted by the patient during rehabilitation (Figure 2).

Modelled on the Facial Action Coding System (FACS) (Ekman, P. et al., 1978) it was decided that 4 sensors placed on each side of the face at key locations could identify all the required muscle groups while allowing asymmetrical monitoring of the patient's facial activity. The four muscles to be monitored are identified as the Frontalis, Orbicularis oculi, Corrugator and Zygomaticus major muscle.

4. SYSTEM OVERVIEW

Based on initial research it was concluded that the project required the development of two hardware prototypes; these two devices are used at different stages in the patient's recovery. The first is a pair of EMG goggles; these are to be used once the patient has started to recover and they are exhibiting movements in previously paralysed muscles.

The second is a pair of glasses used to detect asymmetry across the patients face during voluntary and spontaneous expressions whilst interacting in the real world. These glasses are to be implemented in the last stages of a patient's treatment and are to be used to detect and provide feedback to a patient during involuntary movements while performing everyday activities, e.g. in conversation or watching television in the home.

4.1 Hardware Development

4.1.1 Goggles

The goggles contain eight different EMG sensors placed at key locations on the users face identified by research undertaken in the early stages of the project. EMG sensors detect the electrical activity across the muscles and provide data showing the intensity of the muscles activation. In the early stages of recovery, patients will often find muscles are tensed as they attempt to compensate for the facial palsy, due to the facial muscles not providing feedback to the brain the patient will often be unaware that this is happening. If the patient were tasked with performing exercises at this stage then they would struggle to achieve the desired outcome as they *fight* with their muscles for control. The goggles (Figure 3) are therefore used to provide the patient with a visual representation of this muscle activity; the patient can then be tasked with a number of controlled exercises that will help them to relax all of the muscles in their face.

Figure 3. *Prototype EMG goggles - Oculus VR headset interface enabling multichannel EMG sensing of multiple facial expressions*

4.1.2 Glasses

The glasses frame is designed to integrate a number of sensors into the frame to detect facial movements and expressions, Figure 4 (left). Sensors are integrated into the frame to detect the movement of the cheeks and to detect asymmetry between the left and right side of the wearers face.

The muscle activity sensors are used to monitor movements in the lower regions of the user's face including the Zygomaticus muscles and the Levator Labii Superioris muscles. This movement is used to detect asymmetry in the user's smile, along with detecting involuntary Synkinetic movements made by the patient during other facial expressions.

The muscles sensed using the system in real time are shown on the analysis platform, in Figure 4.

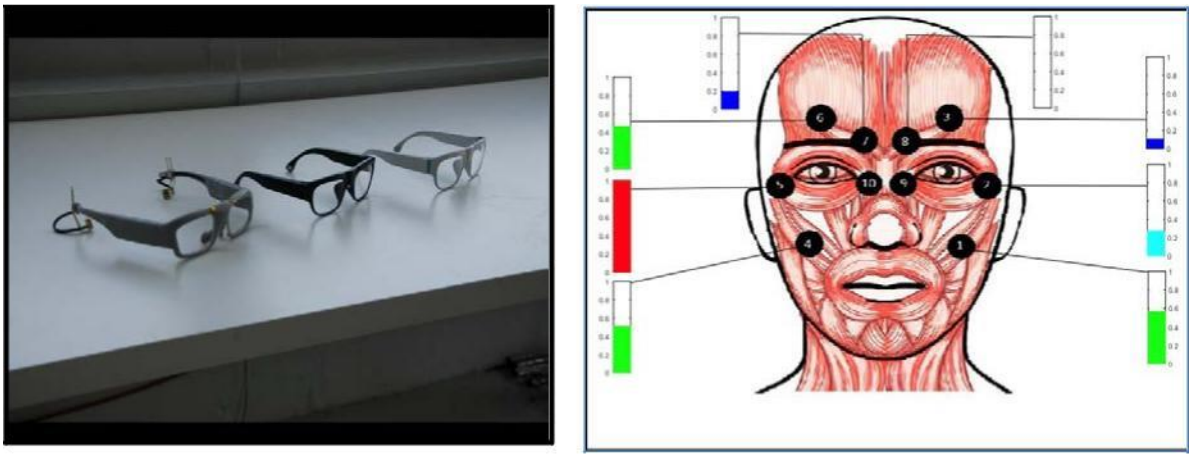

Figure 4. *(Left) EMG glasses prototype with contact sensors on the nose pads and behind the ears. (Right) Screenshot of the EMG analysis dashboard demonstrating increased right facial muscletone (sensor 5 and 6).*

Patients will often demonstrate Synkinetic movements in the eye area, this is known as extra-ocular muscle synkinesis. This manifests as involuntary eye closure during attempts to make expressions. A number of options have been explored for providing sensory feedback to the wearer. A separate prototype containing a tiny vibration unit in the glasses arm and multi-colour LED positioned near the glasses hinge was created to test these options for providing audio, visual or combined feedback. A focus group was convened and volunteers experienced a range of feedback options that they rated. The participants were given the option of short, medium and long bursts of vibrations and/or illumination. It was found that no single combination of modalities was popular with all subjects, and that they most valued the ability to customise the feedback for their own needs.

4.2 Software

It is anticipated that the patient would download a mobile application that will act as the UI (User interface) for the hardware and guide the patient through the required exercises. The mobile application has been developed to work on Android and IOS devices to accommodate for the two most commonly used mobile platforms currently in use. The UI design takes into account the varying screen sizes between mobile phones and tablets, ensuring that the content appears clearly to all users no matter what device they are using. The mobile device uses a web API based system to send and retrieve data from a centralized server hosted on the internet; this server acts as the central repository for all data on the system and provides the ability for a user to use multiple devices without losing their data between sessions. A web portal has been created for the patient's therapists to monitor and modify their patients exercise routines to ensure the best care possible.

4.2.1 Mobile Application

The application (Figure 5) will provide the patient with valuable information and advice throughout their treatment, it will also provide feedback on their current progress allowing the patient to see their improvement over time providing a valuable confidence boost. The application is designed to work on a wide range of mobile devices running both the Android and IOS operating systems. This design will ensure that the patients will be able to install the application onto their own personal mobile device, this will reduce the initial cost of hardware and the amount of time required to train a patient in its use.

The mobile application has a login system that allows the user to create a secure and anonymous account; they can login to this account from multiple devices and can perform their exercises from any of these devices. The monitoring of exercises and achievements is monitored across all their devices and the devices are synchronised using a cloud based web service allowing them to see their results from any of their registered devices.

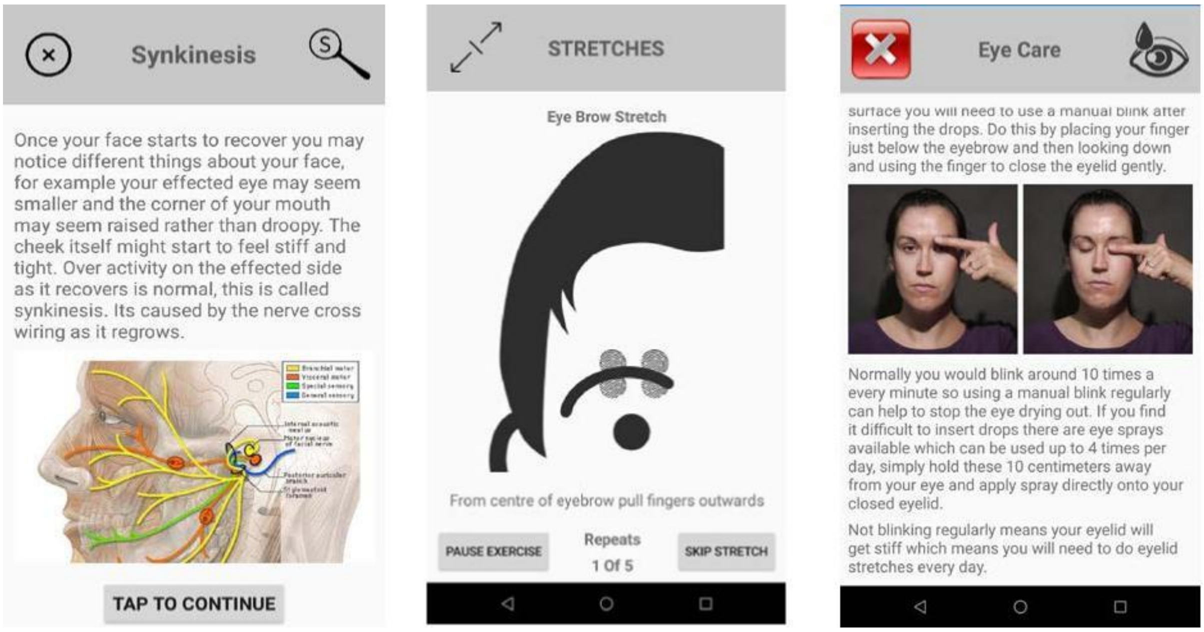

Figure 5. *Mobile Application information and exercise screens*

4.2.2 *Web Portal*

The mobile application is connected to an online database and uploads anonymous data to a central cloud based server. This allows for the remote monitoring of the patient's progress by a qualified therapist who can see their patients progress and adjust any exercise routines as required. It also allows the user to swap between devices during their treatment; the data is stored externally and therefore the device can be swapped and the data preserved.

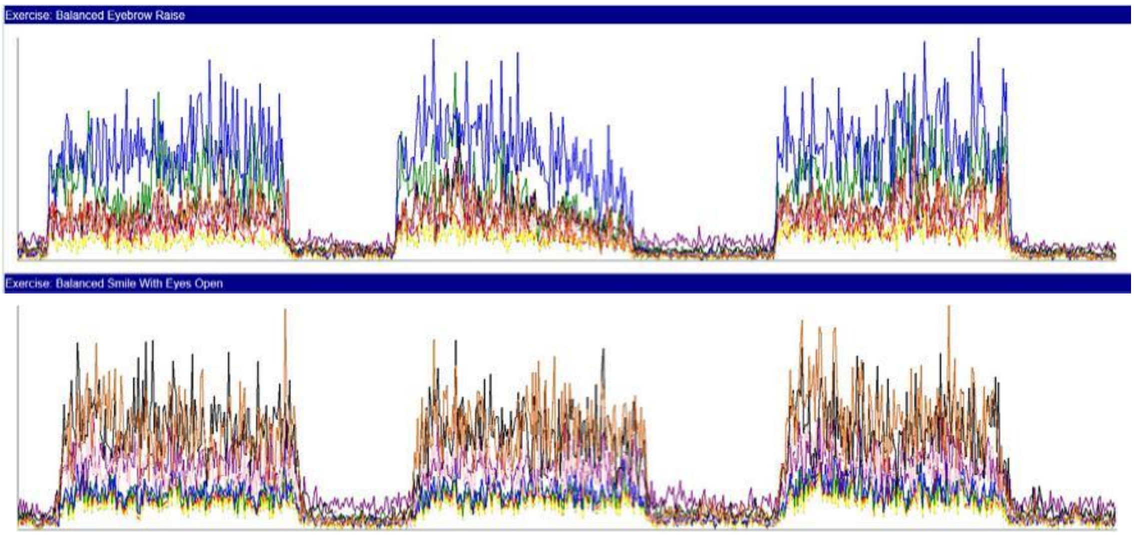

Figure 6. *Web portal shows analysis of EMG results from the Mask taken during patient exercises - generated from data stored securely in the cloud*

Another essential part of the web portal is to provide analysis of the data being collected by the two different hardware prototypes. There is a requirement to collect and upload the data to the server so that it can be accessed by the team who are continuously analysing and adjusting the algorithms to provide the most accurate results possible (Figure 6).

4.2.3 Patient Assessment

An important part of the project is the ability to assess patients by identifying the status of their condition. There is a need to identify the current treatment path that the patient is on and to identify when this path needs to be modified so that the advice and exercises are changed within the application and the therapist is informed of the change so that the mask or glasses can be deployed. The patient assessment will be undertaken in two stages, the first is a simple questionnaire presented to the patient at a set interval (currently two weeks), the patient will answer the questions and the feedback is run through a simple decision algorithm to identify the patient's status and choose the correct treatment path for them.

The second stage is to conduct research into the capability of using facial tracking from the mobile device camera to perform the assessment. The system will use the Sunnybrook facial grading system (Ross et al., 1996) to provide a Sunnybrook score, this score will then be used to identify the patient's status and choose the correct treatment path. The score will also be used to identify small improvements in the patient's condition and potentially flag any issues such as Synkinesis to the patient's therapist.

5. CONCLUSION

The project will ultimately create sensor-enabled glasses for facial expression monitoring that are indistinguishable from a standard pair of glasses. For facial palsy patients this will enable a patient's facial expression rehabilitation. As the project progressed, it became apparent that for the majority of patients there is a need to provide muscle feedback from more locations before progressing to a glasses-based format and a goggle-type arrangement to detect muscle activity directly from the lower region of the face. In addition, as discussions continued with facial palsy specialists it became apparent that there were two essential requirements for patient rehabilitation. The first is the need for the patient to relax their muscles and to allow them to return their muscles to a neutral, relaxed state. The second is used at a later stage in the rehabilitation process to detect synkinesis during involuntary movements exhibited during everyday activity and to alert the user to the unwanted muscle activity.

The first requirement can be best achieved using EMG sensors that show the activation levels of the muscles at the appropriate locations. The patient is given a simple exercise where they attempt to relax their muscles to drop the muscle activation levels to the lowest level possible. It was concluded therefore that contact based EMG sensors are essential in the early stages of rehabilitation.

The use of non-contact optical sensors has enabled muscle activity to be assessed and monitored, albeit at the expense of the ability to monitor EMG signals. It was concluded that at this stage in the research, it would be most effective to develop two prototypes; the first being a pair of goggles to be used in the patient's home. These goggles will contain the eight EMG sensors located at key locations around the patient's face, the goggles will be used in relaxation exercises to train the patient to relax all their facial muscles. Following instructions from the mobile application the patient will then be able to see visual representations of the EMG sensor feedback.

Figure 7. *Optical glasses prototype.*

The second prototype is a pair of glasses that integrate the optical sensors to detect asynchronous movement in the patients face and to provide biofeedback within the frame (see Figure 7). This enables the system to alert the user in real time, enabling them to be able to use the glasses during everyday activities without need to look continuously at a screen/ smartphone. The next stage of development will specifically focus on field trials of the system to assess usability and performance in an *everyday setting*.

6. ACKNOWLEDGEMENT

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Concurrent virtual rehabilitation of service members post-acquired brain injury – A randomized clinical study

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ABSTRACT

The study objective was to determine the feasibility of concurrent training with the BrightBrainer Rehabilitation System while providing improved clinical efficiency and patient access to care in a military clinical setting. The participants trained 6 weeks on a number of custom, adaptable, therapeutic games. An occupational therapist supervised the one-on-one and concurrent (one-on-two) treatment interventions. Training consisted of using a uni-manual play in the first week, followed by bimanual interaction (involving higher cognitive load), and the addition of wrist weights in weeks 2-6. Initial study findings demonstrated that with continued practice, participants were able to increase the intensity of play (repetitions/minute), and improve their performance on a subset of memory and attention games. Furthermore, proof of concept was established to demonstrate concurrent training in nearly half of the training sessions recorded. There was no reduction in training intensity or game performance when training concurrently.

1. INTRODUCTION

Concurrent therapy in rehabilitation is a term used in billing services for situations when one therapist trains two patients at the same time (Center for Medicare Services, 2017). Concurrent *virtual* rehabilitation describes a scenario when the two patients are immersed in virtual environments of a therapeutic nature. Concurrent training represents a newer area of virtual rehabilitation, currently under investigation.

It is intuitive that concurrent virtual rehabilitation, if successful, presents clear advantages that supplement those of virtual rehabilitation itself (Burdea, 2003). One of these additional benefits stems from increased access to care in instances where the available therapists cannot meet caseload demand. Another is a reduction in care costs (mainly personnel). Finally, increased socialization through games is facilitated when both patients share the same virtual environment.

On the flip side, management needs to ensure that quality of care is not diminished when two (side-by-side) patients are overseen by a single therapist. The patients' compatibility and level of assistance needed are important elements when determining who can be trained concurrently. Just as important is the willingness of the independent therapist to have a higher physical and cognitive demand when training two patients at the same time.

In a scenario when two individuals (whether patient and therapist, patient and healthy relative, or patient and patient) interact simultaneously with a therapeutic virtual environment, three possible settings occur: a) competitive play (the two patients play against each other); b) cooperative play (the two patients help each other); and c) individual play (each of two collocated patients plays individually against their computer). A recent study compared the intensity and motivation of competitive vs. cooperative games used in arm rehabilitation (Goršič et al., 2017). Researchers found that both types of game play were motivating, however the intensity of play was (as expected) higher in competitive play.

The present paper details aspects of a recently completed randomized clinical study on integrative virtual rehabilitation conducted at a large military medical center in the US. The study targeted service members post traumatic brain injury (TBI) and/or acquired brain injury (ABI)/stroke. The participants received training on the BrightBrainer Virtual Rehabilitation System (Burdea et. al., 2015), in which a portion of the therapy was completed concurrently. The particular form of concurrent training was individual interaction with similar virtual environments rendered on systems placed side-by-side. The software used had been designed for input from a single user, thus competitive or collaborative concurrent training was not feasible. This paper focuses on computer game performance, training intensity (which are non-standardised outcomes), as well as therapist's impressions. This is part of a larger study which measured clinical outcomes based on standardised evaluations, with results presented elsewhere (Buccellato et al., 2018b).

2. METHODS

2.1 The BrightBrainer Rehabilitation System

The BrightBrainer Rehabilitation System is an integrative training platform, in which both cognitive and motor impairments of a patient are trained simultaneously using therapeutic games.

Participants' interaction with the therapeutic games was mediated by a pair of game controllers with the magnetic base station placed in front of the computer (Figure 1). Two systems were placed on a non-metallic table to minimize tracking interference caused by Eddy currents occurring in nearby metallic objects. Each participant used digital wireless headphones to prevent game sounds from being masked by ambient clinic noise. A partition board was placed between the two BrightBrainer systems, so to help focusing during concurrent face-to-face, but individual play. The system used in this study is the precursor to BrightBrainer BBX, a class I medical device currently marketed by Bright Cloud International (www.BrightBrainer.com).

A library of 11 custom therapeutic games created by Bright Cloud International in Unity 3D (Unity Technologies, 2017) was used to interactively train the participants. Upper extremity training was first done uni-manually, then both arms were used for higher level of exercise. These games were *Breakout 3D*, *Card Island*, *Kite*, *Tower of Hanoi*, *Pick & Place*, *Treasure Hunt*, *Submarine Rescue*, *Arm Slalom*, *Xylophone*, *Avalanche* and *Musical Drums*.

Figure 1. *The BrightBrainer Rehabilitation System in a Military Outpatient Occupational Therapy Clinic. © Bright Cloud International. Reprinted by permission.*

Each game involved manipulation of avatars in 3D, as well as index finger flexion/extension, when performing certain tasks. Avatar manipulation was done through arm movements in 3D space, while index flexion/extension was used to pick up virtual objects or to activate avatar properties (as detailed below). Games targeted both the cognitive (short term memory, focusing, executive functions, reading comprehension) and motor (control, endurance, and strength of the arms, shoulders, core and finger flexion) domains. Each game adapted to the participant at every session, though a process of arm reach and index finger range baselines. Furthermore, games had settings to accommodate participants who could not use their index to press the controller button so to grasp virtual objects or to trigger avatar properties. In those instances object selection was based on a 2-second hover time above that object. For example, in the *Card Island* game, once a hand avatar had hovered 2 seconds above a card, it would flip face up to reveal its image. Furthermore, each game had between 10 and 16 levels of difficulty, ensuring good variability so to combat boredom and keep participants challenged. The resulting participants' motivation was evidenced by their subjective evaluation of the system, desire to continue playing at the completion of the 6-week training protocol, as well as therapist's observations.

Games induced a large number of movement repetitions and contributed to shoulder and core strengthening when wrist weights were added.

The use of bimanual interaction increased cognitive load as well as blood flow to the upper body. Cognitive training (which was the primary goal for the study population) was enhanced through task sequencing (arms taking turns doing a task), and dual tasking (attention was split between a purely motor task and a simultaneous more cognitively demanding task (McIsaac and Benjapalakorn, 2015). Bimanual interaction was also important to increase focus and concentration which are problematic areas for individuals post-TBI. For example, in the *Breakout 3D* game (Burdea et al. 2013) (Figure 2*a*) participants were asked to bounce a ball between paddle avatars and an array of crates placed on an island. The goal was to destroy all the crates and win the game. The difficulty of this game related to ball speed (progressively faster), paddle size (progressively shorter) and number of crates to destroy (progressively more). Tasks sequencing meant each arm took turns bouncing the ball, while dual-tasking (used at higher levels of difficulty) meant that the participant had to remember to press the controller trigger precisely at the moment of bounce, lest the ball passed right though the paddle and became lost.

Submarine Rescue (Figure 2*b*) (Burdea et al., 2015) was a game that primarily trained executive function, namely arithmetic problem solving. The scene depicted the inside of a damaged submarine with water gushing in and an array of numbered crates. The participant needed to lighten the submarine, by removing crates one-at-a-time and placing them in an exit port for flushing. The current and next shallower depths were displayed, and the correct crate to remove was the solution of a subtraction equation between the two depths. Thus the participant needed to perform the subtraction sequence until the submarine surfaced. At higher levels of difficulty the volume of water gushing in was so large as to cover the numbered crates. In that scenario the participant had to use the other arm to pump water out, something that trained split attention. A video showing some of these games being played can be found online.

a) b)

Figure 2. *Therapeutic games used in BrightBrainer training in a military OT clinic: a) Breakout 3D (Burdea et al., 2013); b) Submarine rescue (Burdea et al., 2015). © Bright Cloud International. Reprinted by permission.*

An automatic session report was developed so to capture participant ID code, level of supervision required by the OT (one-on-one or two at once), playing modality (uni-manual or bimanual), wrist weights size (when used), games played, their difficulty levels and scores. Additionally, the session report provided counts of arm repetitions and finger flexion for each arm, total session time, total exercise time and total training time for each cognitive domain. Other variables reported were game scores, training intensity (number of repetitions/minute), error rates, blood pressure and pulse, as well as therapist notes. The session report provided graphing to store arm and finger range baselines, as well as compare multiple sessions to objectively gauge participant's progress.

2.2 Training Protocol

The study had two arms, with an experimental group receiving customary care plus six weeks of BrightBrainer training. The wait-list control group had three weeks of customary care before start of the experimental therapy (Murphy et. al. 2017). Each week of experimental training had three sessions of virtual rehabilitation (Figure 3).

Over the 6 weeks of experimental training the play duration was to increase from 30 minutes/session in week 1, to 40 minutes of actual play in every session of the last 4 weeks of training. The protocol stipulated that concurrent sessions provide a total of 480 minutes of actual training for each of two participants, while being supervised by one clinical or research staff. Two sessions were considered concurrent if there were at least 10 minutes of overlap out of the total session duration.

In order to determine if concurrent virtual rehabilitation was possible with the BrightBrainer system, participants were to be paired based on scheduling availability, as well as functional levels. No two severely impaired participants were to be paired for concurrent training. The participants were to be assisted by an occupational therapist one-on-one during the first two weeks (a total of 6 sessions). Subsequently, two collocated participants, were to train independently on two BrightBrainer systems under the supervision of a single therapist for four weeks (12 sessions).

Session game composition similarly were to increase, from 6 different games in the first week to 11 games in the last week of therapy. In other words every week introduced a new game, so to maintain participant interest and engagement. The game difficulty was also to progress from "easy" to "demanding," such that no two weeks of training were the same. Additionally, wrist weights were to be used for core, shoulder and arm strengthening, incrementally increasing, from 0.5 lb in week 2, to 3 lb in weeks 5 and 6.

2.3 Subject Characteristics

The study inclusion criteria were: military health care beneficiaries 18-67 years of age, presence of TBI or ABI/stroke that occurred at least six weeks prior to participation, good or corrected vision and hearing, ability to comprehend the consenting process, to understand instructions and the English language. Due to the adaptable and integrative nature of BrightBrainer therapy, upper extremity dysfunction (limited or decreased coordination , increased tone, decreased strength, or decreased sensation) did not constitute reasons for exclusion.

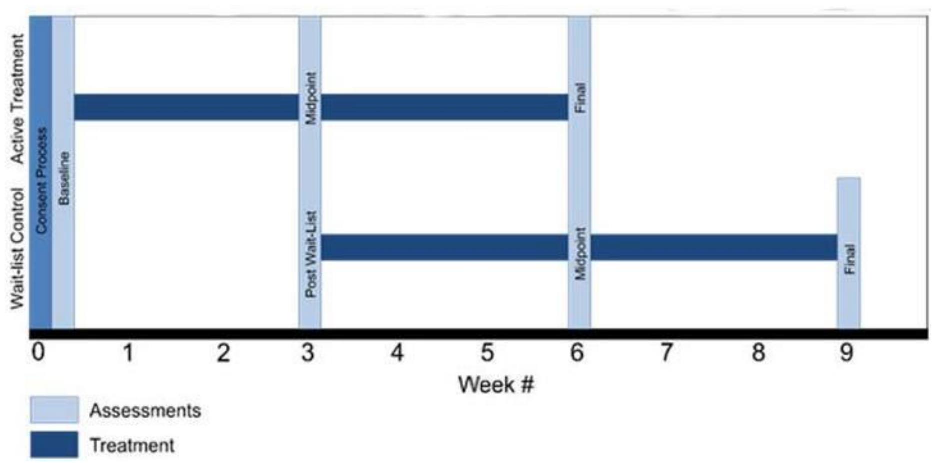

Figure 3. *Therapeutic protocol of the randomized controlled study (Murphy et al. 2017).*

Participants who were younger than 18 or older than 67, or were blind or deaf were excluded. Inability to comprehend the consent procedure, active psychosis, suicidal or homicidal thoughts, violence, drug addiction, alcoholism or inability to minimally operate the game controllers constituted reasons for exclusion.

Subsequent to approval from the Walter Reed National Military Medical Center IRB, 26 participants were consented. Of these 21 completed the study and one subject withdrew from the study due to scheduled surgery. Two subjects were unable to fit three sessions a week into their schedule, and thus dropped out. One subject was lost to follow up after not attending scheduled sessions. One other subject started training, but left the study early due to sensitivity to light and migraines after treatment sessions. Their incomplete data were not used in the outcome analysis.

Of the 21 (active treatment [AT]=11, waitlist control [WLC]=10) participants who completed the study, 13 were post TBI (AT=7, WLC=6), 4 were post ABI/stroke (AT=2, WLC=2) and 4 had both TBI and ABI/stroke (AT=2, WLC=2). The gender distribution was 15 males and 6 females, with an average age of 41 years (STD=12.31 years). The 21 subjects averaged 15.5 years (SD=2.2 school years) of formal education.

2.4 Data Collection Instruments

Participant and therapist acceptance of the technology was measured with the USE standardized questionnaire (Lund, 2001), as well as custom subjective assessment questionnaires. These custom questionnaires consisted of 10 questions, each rated on a 7-point Likert scale (Joshi et al., 2015).

Non-standardized measures were sampled transparently by the BrightBrainer system. These data included counts of arm repetitions and index finger flexion/extension for each arm and hand, total session time, total exercise time (session time minus rest periods and set up time) and total training time for each targeted cognitive domain. Other variables measured were game scores, training intensity (number of repetitions/minute), game performance, game composition, game difficulty levels and how many times each game was played in a given session.

3. RESULTS

The first participant started training in June 2016, and the last one completed the BrightBrainer therapy in December 2017. Over the 6 weeks of integrative virtual rehabilitation participants played on average a total of 382 games, lasting an average total of 349 minutes. The average length of most games was under 1 minute, except for *Kites* which lasted on average 2 minutes and *Breakout 3D* which lasted 2-5 minutes, depending on participant's skill and game difficulty level.

3.1 Game-induced repetitions

The participants exerted an average total of 27,551 arm repetitions (summing both arms), with session averages progressing over the 6 weeks of therapy based in part on session duration (Fig. 4*a*). Game characteristics as well as how many times a game was played in a session also played a role. For example repetitions induced by *Card Island* game were less than half those for *Breakout 3D* (Fig. 4*b,c*) which lasted longer and had two versions. Participants had an average total of 10,072 index finger flexion/extensions across the study. This finger repetition average number was adjusted based on 19 subjects, since two participants' motor impairment prevented them from using their index in game play.

Since participants were to train concurrently 12 sessions (3 sessions/week for 4 weeks) and there were 10 pairs of participants, there were to be 120 instances of concurrent training. Post-hoc database analysis compared game time stamps for the two systems in order to determine overlap. Concurrent sessions were considered those with time overlap of at least 10 minutes (out of 40 minutes of play), under the supervision of a single therapist. This analysis revealed that only 57 such concurrent sessions occurred.

3.1 Training Intensity progression

Game play "intensity" was computed as the frequency of arm or index finger use - that is, intensity was the number of repetitions divided by the corresponding session duration (in minutes). The session-average intensity was computed in terms of the median and interquartile interval (IQI) of each session among all of the participants. Each session's point estimate and IQI correspond to the distribution of intensity for that session, irrespective of whether any game was played in solo or concurrent sessions. The increase in session intensity in terms of arm repetitions is seen in the left panel of Figure 5, with the linear ordinary least squares (OLS) estimate of longitudinal improvement of 1.2 points per session ($p<0.001$), represented by the dashed line. A similar progression for index finger flexion/extension repetitions is featured in the right panel of Figure 5, with the linear OLS estimate of longitudinal improvement of 0.73 points per session ($p<0.001$). There was an increase in variance of intensity scores across sessions for the arm, as well as for the index finger: Breusch-Pagan test of heteroskedasticity p-values of 0.008 and < 0.001, respectively. This is indicative of the participants varying skills as well as less uniformity in their ability to sustain intensive play at higher levels of game difficulty.

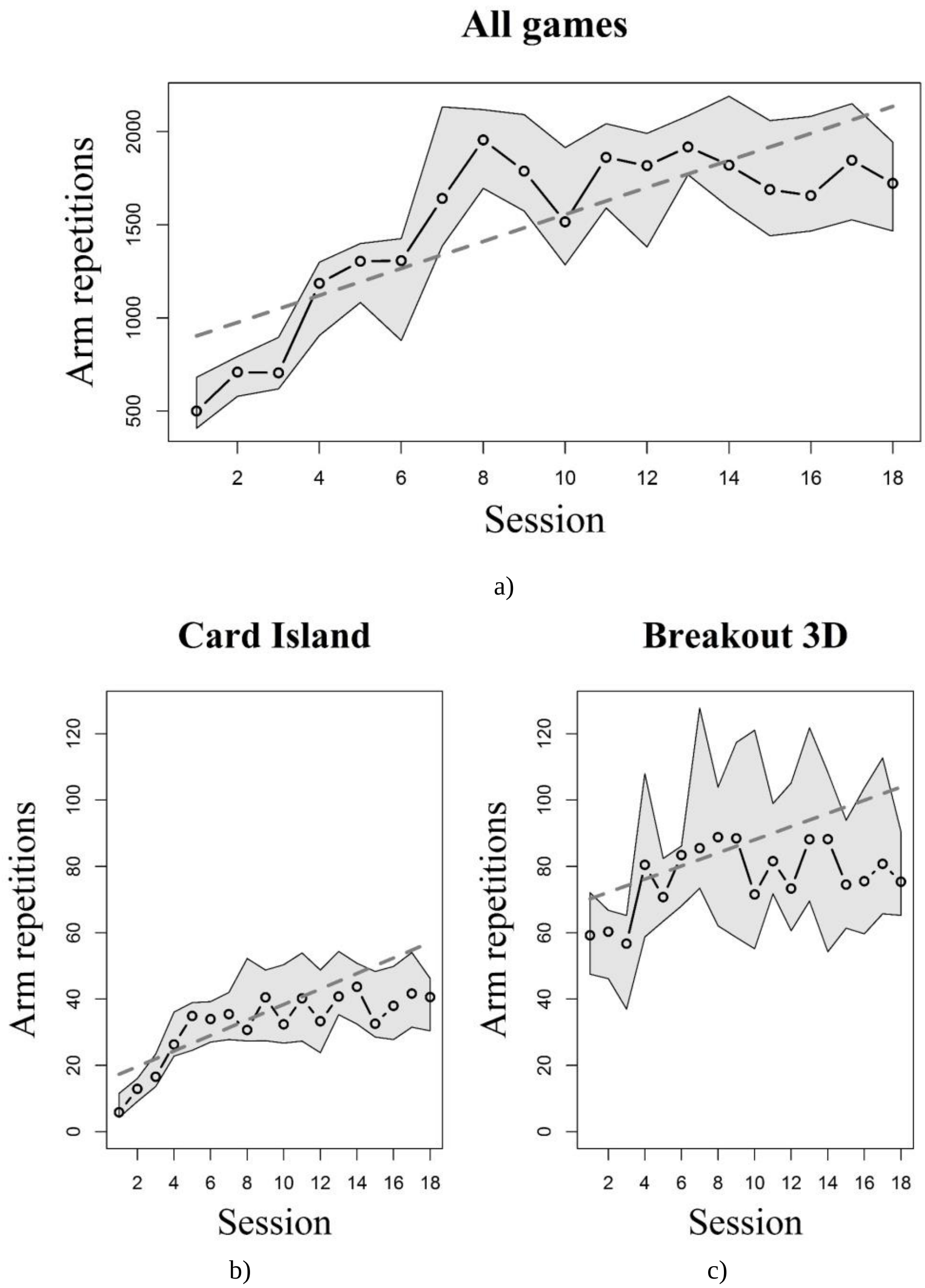

Figure 4. *Combined groups average arm repetitions over 6 week intervention: a) arm repetitions for all games in a session; b)* Card Island *group average arm repetitions; c) group average arm repetitions when playing* Breakout 3D*. © Bright Cloud International. Reprinted by permission.*

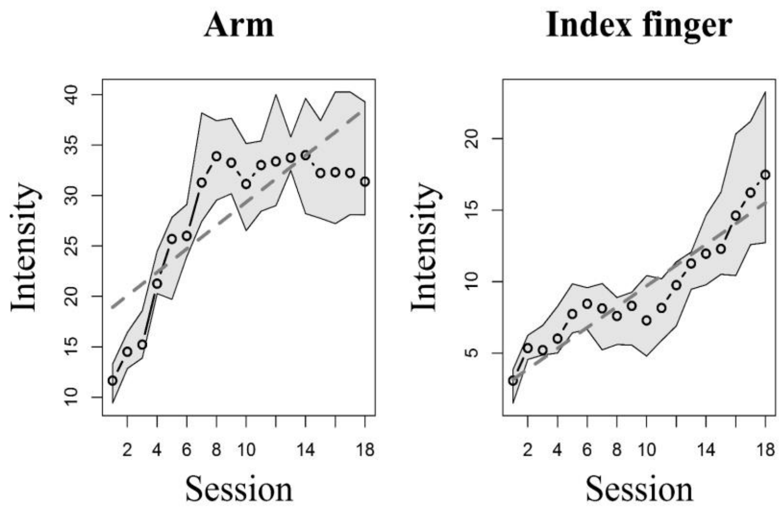

Figure 5. *Longitudinal change in intensity of therapeutic games of BrightBrainer training; the session-average median efficiency score is represented by the connected dots, and the shaded region represents the corresponding interquartile intervals; the dashed line represents the linear ordinary least squares estimate of the longitudinal change. © Bright Cloud International. Reprinted by permission.*

3.2 Game performance progression

Game play performance was computed as the average of game scores for all games played in a given session. As stated in the Methods section, the number of different games available for play increased steadily from 6 in week 1 to 11 in week 6. In order to have consistency in game performance analysis, it was necessary to select games played on all sessions. This means that selection was obtained from the 6 games introduced in week 1.

A further constraint for game analysis related to the patient population being enrolled in the study. Patients post mild, or moderate TBI are affected primarily in the cognitive domains of focusing and memory (Key at al., 1993). As such. From among the games that started in week 1, this paper considers *Card Island* (training short term visual and auditory memory) and *Breakout 3D* (training focusing). Their longitudinal change in game performance over six weeks of therapy is shown in Figure 6.

The session-average game performance was computed in terms of the median and interquartile interval (IQI) of each session among all of the participants. The linear ordinary least squares (OLS) estimate of longitudinal improvement in performance for *Card Island* was 1.3 points per session ($p<0.001$), while that of *Breakout 3D* was 13.3 points per session ($p<0.001$). Moreover, we observed an increase in variance of performance scores across sessions for the *Breakout 3D* game (Breusch-Pagan test of heteroskedasticity p-value < 0.001), but not for *Card Island* (Breusch-Pagan test of heteroskedasticity p-value of 0.971). This may be due to the difference between game characteristics (with *Breakout 3D* emphasizing speed of response, while the emphasis in *Card Island* was short-term visual/auditory memory). The frequency of change in game difficulty was lower for *Card Island*, which may also reflect the flattening of the performance curve in later sessions.

3.3 Therapist impression of BrightBrainer concurrent sessions

The OT who trained the majority of participants (a co-author of this paper) believed that the games used in the training sessions were both classic and intuitive in nature. It was easy to complete the activities unless there was a metal object or an active Blue Tooth emitter anywhere near the game controllers (a known issue with Hydra controllers). Learning to recognize common errors based on how the avatar moved on the screen took time. The therapist's confidence to problem solve technical challenges, while simultaneously engaging the participant in a positive and productive treatment sessions independently, also improved over time. There were very few treatment sessions which required rescheduling due to technical challenges.

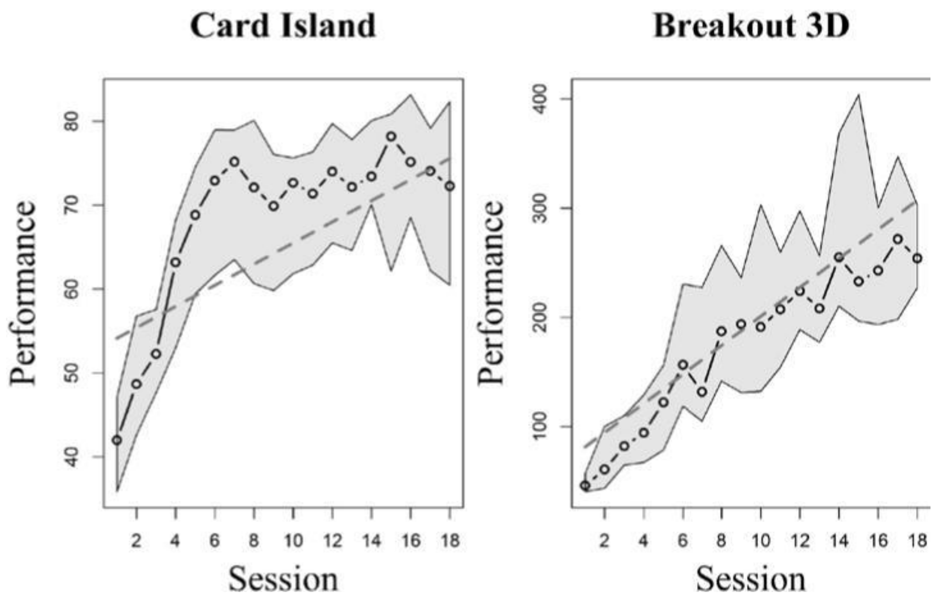

Figure 6. *Longitudinal change in performance of therapeutic games during BrightBrainer training; the session-average median game performance is represented by the connected dots, and the shaded region represents the corresponding interquartile intervals; the dashed line represents the linear ordinary least squares estimate of longitudinal change. © Bright Cloud International. Reprinted by permission.*

When performing concurrent sessions it was critical to utilize a 10 to 15 minute staggered participant schedule. This time allowed for daily baseline, configuration of the controllers (required approximately 5 minutes), education on new games (2 minutes) and the opportunity for the participant to demonstrate understanding of a new game (2 minutes). This gap also ensured time to answer any questions, problem solve any technical issues (with the computer or therapeutic games), and created a time cushion for participants who were possibly running late.

If both participants were high functioning (physically and cognitively) there was very little for the therapist to do and running a concurrent session was feasible. When the participant required continuous redirection, cues, physical assists or modifications to reduce glare, the ability to provide quality care for more than one participant at a time became very challenging. However, having an assistant available to manage the technical challenges ensured the sessions were successful.

Recruitment, patient schedules, and medical issues were a continuous challenge when attempting to book two participants concurrently. A few of the participants barely tolerated a 30 minute session due to light and screen sensitivity. Even though they performed the entire session, the training session likely did not count as concurrent because they did not spend 10 minutes or more in the active play mode simultaneously with another participant for that training session. This is one reason why the number of sessions considered to satisfy concurrency was smaller than the theoretical number based on protocol.

The participants' and therapist's evaluation of the technology usability and perceived clinical benefit as evidenced by their subjective evaluations was very favourable (72-85%). (Buccellato et al., 2018a).

4. DISCUSSION

Looking at the graphs in Figure 5 it seems that concurrent training did not affect the game play intensity. While available study data is limited (in part due to the relatively small number of participants) as well as occasional technology issues, the intensity of play seemed to continue increasing during concurrent sessions. More studies, and more accurate tracking data will (in the future) allow for more definite analysis of concurrent virtual rehabilitation.

Another aspect that warrants discussion is the influence of the number of difficulty levels on the game performance graphs. Looking at Figure 6, the reader observes that group game performance when playing *Card Island* seemed to plateau about mid-way through the therapy. By contrast, group performance in the *Breakout 3D* had a steady increase over the length on training. There were more levels of difficulty in *Breakout 3D* game (due -for example, to progressively faster speeds the ball traveled, progressively smaller paddles, and dual tasking condition of remembering to squeeze the game controller trigger before ball bounce at higher levels of difficulty). This compared to the levels of difficulty for *Card Island* which depended on number of cards to be paired (2 pairs, 4 pairs, 6 pairs, and 8 pairs) as well as the progressive removal of cognitive cues (such as different color of the question mark on the back of cards already seen).

If participants achieved the highest level of difficulty early in their training, it was only through making fewer errors and having shorter game completion times that they could achieve higher game performance.

This study examined the benefits of VR training on the BrightBrainer system, as well as ability to integrate the system in a military outpatient clinic settings. It is likely that some neural rewiring occurred owing to the large number of arm repetitions needed for game play, and the bimanual nature of play. Figure 4a graph shows an average 900 repetitions for each arm (about 1,800 total) in the last 3 weeks of the virtual rehabilitation. This is *28 times more* than the 32 repetitions observed in customary UE rehabilitation for stroke populations (Lang et al., 2009). However, in the absence of brain imaging it is not possible to confirm the authors' hypothesis that there were neural paths changes in the present study participants.

Some of the challenges mentioned by the training OT stem from the limitations of magnetic tracking used by the Hydra game controllers. In the two years that passed since the study had started, the tracking technology has evolved substantially. The modern BrightBrainer BBX system uses the HTC VIVE game controllers (HTC 2016). The VIVE does not use magnetic fields, thus it is impervious to interference from metal objects in the vicinity, or to the presence of other magnetic field sources nearby. Other advantages of the new tracking technology are much more precise tracking and wireless tracking. The elimination of the cables used by the Hydra controllers means that today a more natural and unencumbered arm movement is possible.

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Meaningful change: defining the interpretability of changes in endpoints derived from interactive and mHealth technologies in healthcare and clinical research

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ABSTRACT

Immersive, interactive and mHealth technologies are increasingly being used in clinical research, healthcare and rehabilitation solutions. Leveraging technology solutions to derive new and novel clinical outcome measures is important to the ongoing assessment of clinical interventions. While demonstrating statistically significant changes is an important element of intervention assessment, understanding whether changes detected reflect changes of a magnitude that are considered meaningful to patients is equally important. We describe methodologies used to determine meaningful change, and recommend that these techniques are routinely included in the development and testing of clinical assessment and rehabilitation technology solutions.

1. INTRODUCTION

Miniaturization of sensors and circuitry has given rise to huge proliferation in the development and commercialization of wearable and sensor-based technologies with application to health and wellness. Much research and development activity has involved the application of interactive and immersive technologies in the areas of healthcare and rehabilitation. Immersive technologies are those that merge the physical world and the digital or simulated world, thereby creating a sense of immersion, such as virtual reality (VR) applications. In healthcare, VR systems, for example, have shown promise in improving outcomes such as muscle balance, dexterity and grip in comparison to traditional rehabilitation in upper limb rehabilitation after spinal cord injury (Dimbwadyo-Terrer et al., 2016), and to improve the emotional health of cancer patients and decrease associated disease-related psychological symptoms (Chirico et al., 2016). Applications using motion-based gaming platform technology, in particular using the Microsoft Kinect® (Microsoft Corp., Redmond, Washington, USA), have been reported to provide therapeutic benefits in areas such as stroke (Sin et al., 2013), Parkinson's disease (Galna et al., 2014), multiple sclerosis (Ortiz-Gutiérrez et al., 2013) and cerebral palsy (Luna-Olivia et al., 2013). Mobile Health (mHealth - the use of mobile and wireless devices to improve health outcomes, healthcare services and health research (HIMSS, 2012)) solutions have, for example, been reported to improve outcomes such as working memory, concentration and interference processing in children suffering from attention-deficit hyperactivity disorder (ADHD) (Bashiri et al., 2018).

In addition to providing the basis for new treatment interventions, interactive technologies are being utilised to develop new ways to measure health outcomes in clinical research. This enables researchers to track and monitor changes in health status over time, or resulting from treatments such as the application of new pharmaceutical products. For example, the Microsoft Kinect has been used to measure performance-based health outcomes such as measures of gait and balance in indications including multiple sclerosis (Behrens et al., 2014; Pfister et al., 2014), stroke (Clarke et al., 2015) and Parkinson's disease (Galna et al., 2014), and measures of upper extremity range of motion in adhesive capsulitis (Lee et al., 2015) and stroke (Olesh et al., 2014). mHealth applications, in particular those leveraging the inbuilt sensors and components of modern smartphones, have been used to measure new and novel health outcomes in a variety of indications, speeded by the availability of platforms such as Apple ResearchKit and Google StudyKit. For example, Roche Pharmaceuticals (Basel, Switzerland) has developed an innovative mHealth platform and app that enables the measurement of a number of health outcomes via active performance tests conducted by the patient. These leverage Android smartphone components including the accelerometer, gyroscope and touchscreen (Gravitz, 2016). Roche have recently implemented this application to study phonation, tremor, balance, gait and dexterity in Parkinson's disease clinical trials (Lipsmeier et al., 2017).

Over the past two decades, clinical drug development programs have become increasingly complex and have included a greater volume and variety of assessments and clinical procedures. In particular, there has been increased interest and uptake in the use of new technologies, including gaming platforms and sensor-based solutions to provide richer information on the efficacy and safety of new potential medications. Pfizer (New York, NY), for example, has recently reported positive results from a study evaluating the measures of multitasking and interference processing performance collected while using the Project:EVO videogame (Akili Interactive Labs, Boston, MA) as biomarkers to enable the selection and longitudinal assessment of Alzheimer's patients (Wright et al., 2017). Clinical drug developers are also seeking to understand how to leverage other interactive technologies to measure and track intervention effects, including (for example) wearable sensors, motion-based gaming platforms and VR applications.

Healthcare solutions, clinical research and clinical trials rely upon robust and validated methodologies to measure health status and to detect treatment-related changes over time. This enables the efficacy and safety of new interventions to be accurately assessed and measured. In some cases, these evaluations rely upon subjective assessments by the investigator or the patient. While important, in some instances these subjective measures may not be sensitive enough to detect treatment-related changes and may be unable to conclusively demonstrate treatment effects when they exist. Leveraging mHealth and interactive technologies may provide an opportunity to supplement treatment evaluations with new, novel and objective health outcome measures that may permit increased precision to detect treatment effects, and enable the measurement of constructs not previously possible. Understanding the clinical relevance of changes detected is of vital importance to understand if an intervention is producing the magnitude of change that will be seen to impact patients.

In this article we explore a recommended approach to defining meaningful change in new health outcome measures. This is an element that is largely overlooked in the development and assessment of immersive, interactive and mHealth technologies developed as interventions and technologies to measure health status. We recommend that this becomes a component of rehabilitation and clinical assessment solution development and testing when using immersive, interactive, wearable and mHealth technologies.

2. CLINICAL OUTCOMES AND ENDPOINTS

Clinical outcomes are measurable characteristics influenced by an individual's baseline state or an intervention (FDA, 2016). These might include estimates of functional reaching volumes within immersive game-driven applications, free-living activity measurements using an accelerometer, or dexterity measures using an mHealth tapping test on a mobile phone. Outcome assessments are used to define efficacy endpoints when developing a therapy for a disease or condition. Interactive and mHealth technologies have the potential to produce many possible clinical outcome measures, and determining those important in measuring pertinent aspects of health status that are important to the patient or condition studied is essential.

A clinical endpoint is defined as: "*A characteristic or variable that reflects how a patient feels, functions, or survives*" (The Biomarkers Definition Working Group, 2001). Endpoint descriptions should also include a definition of how and when they are measured, how they are calculated from outcome data, rules for missing data, and how they should be analysed. For example, an endpoint derived from the outcome data collected using a wearable continuous glucose monitor may be the change from baseline in mean daily time within target range measured over a 7-day interval after 12 weeks of treatment.In regulatory clinical trials, an endpoint model is required to be defined within the study protocol and regulatory submission materials. This model will detail each study concept of interest, and identify how the endpoints selected relate to each concept, and indicate which endpoints are primary (that the study is powered to adequately assess), secondary and exploratory. Understanding how to interpret changes measured in study endpoints is an important component of the assessment of any intervention, whether a pharmaceutical treatment or a healthcare/rehabilitation solution.

3. INTERPRETABILITY

3.1 Meaningful change

Meaningful change can be considered to represent the smallest difference in an endpoint measure that would be perceived by patients as beneficial. For many new and novel endpoints derived from the new application of technologies, this understanding of meaningful change thresholds may not already exist. It will be important to assess this if the approach is to be used to measure and monitor changes in health outcomes. In this section on interpretability, we use the illustration of a clinical endpoint measuring activity derived from the output of a wearable step-counting device, as very few published examples exploring meaningful change for other mHealth and interactive technology solutions exist.

Meaningful change is likely to be different between patient populations. For example, in an mHealth intervention measuring and encouraging stepping activity, measures of meaningful change in the number of steps walked per day are likely to be lower in less active patient populations such as those suffering from chronic obstructive respiratory disease (COPD) compared to more active groups, such as type 1 diabetics, where the average number of steps per day has been reported to be 2,237 and 8,008 steps/day respectively (Tudor-Locke et al., 2011).

While the importance of statistical significance in demonstrating the effects of an intervention is unquestioned, it is also important to recognise that effect sizes detected through statistical tests may be of insufficient magnitude to be considered relevant to the patient. Understanding the threshold for meaningful change (also referred to as clinically relevant change) is important when interpreting any statistically significant effect sizes detected.

This meaningful change may be represented by the minimal important difference (MID), also called the minimally clinically important difference (MCID), or by the minimal individual change that distinguishes a responder (an individual exhibiting a meaningful improvement) from a non-responder. The MID/MCID represents the minimum change in group means considered clinically relevant; whereas the individual responder definition represents the magnitude of individual change considered clinically relevant.

In general, the responder definition is useful in interpreting the results at an individual patient level: for example, by determining the proportion of patients that achieved the defined responder definition. This is arguably easier to interpret than an effect size resulting from an analysis of group mean differences. However, on account of the loss of information associated with converting a continuous measure to a binary outcome, and the associated loss of statistical power (Lin, 2016; Snapinn et al., 2007), the analysis of group mean changes in outcome measures derived from interactive and mHealth technologies in clinical trials remains of primary importance. Responder analyses typically provide helpful complementary context and interpretation. The analysis of group mean differences will also typically drive clinical intervention study power calculations where it is appropriate to power studies based on this endpoint.

The MCID and responder definition of change provide similar but not identical values: the MCID is defined in terms of differences in mean scores, whereas a responder definition is considered by evaluating individual changes. The responder definition could therefore be larger or smaller than the MCID depending on the degree of change considered. It is recommended that when identifying the amount of change that is meaningful to patients, researchers should aim to estimate both the MCID and one or more individual responder definitions. Both of these provide useful information in terms of both study design and interpretation.

3.2 Measuring meaningful change

There are a number of approaches that have been reported with which to demonstrate the clinical relevance of change observed with an outcome measure. These include consensus-based, anchor-based and distribution-based methods, as described below.

3.2.1 Consensus-based methods

Consensus-based methods utilize an expert panel of clinical and domain experts to define a threshold for clinically relevant change in the specific patient population to be studied. Typically, consensus approaches use techniques such as Delphi methods that operate in an iterative manner. Using Delphi methods, each panel member provides an initial estimate of the MCID along with the rationale guiding their choice. Panel members then review all estimates and explanations, via a blinded summary provided by a facilitator, and are encouraged to revise their estimates based on the responses of other panel members. Iterating this process typically results in a consensus value being reached.

This approach, while helpful in obtaining agreement on the clinical relevance of an endpoint per se, may be less able to determine the true meaning of changes observed. Where possible, consensus methods should not be solely relied upon to estimate the MCID or responder definition for clinical data interpretation.

3.2.2 Distribution-based methods

Distribution-based methods leverage understanding of the distribution of the outcome measure recorded to identify the magnitude of change that would be unlikely to be observed by chance alone. It is common to use more than a single distributional method to obtain a consensus or range for the MCID value. A number of distributional methods exist including the standard error of measurement (SEM), empirical rule effect size, Cohen's effect size and 0.5 × baseline standard deviation (see Demeyer et al., 2016 for example, Table 1). It should be noted that distribution-based methods of estimating MCID and responder definition can often be less able to determine robust estimates when sample sizes are small or when there is large variability of data at baseline.

Despite their inherent simplicity, distribution-based methods, however, fail to associate statistical changes with whether a truly meaningful change has occurred. Along with other authors (e.g., McLeod et al., 2011), we agree that distribution-based methods should be considered supportive to anchor-based methods (see below) as opposed to providing primary measures of MCID and responder definitions. However, in some circumstances, anchor-based approaches may not be possible due to the lack of a suitable anchor measure, and it may be necessary to rely more heavily on this approach.

A good example of determining meaningful change using wearable technology to measure physical activity levels is reported by Demeyer et al. (2016). They used distribution-based methods to estimate the MCID in total daily steps recorded using an accelerometer amongst COPD patients after pulmonary rehabilitation. They reported the MCID in this population as between 600 and 1,100 steps/day based on the range of values obtained using a variety of distribution-based methods (Table 1). While these values may be high when compared to the average steps per day achieved amongst COPD patients reported elsewhere, estimated to be 2,237 steps/day (Tudor-Locke et al., 2011), the clinical importance of improvements of at least 600 steps/day was further demonstrated by reduced risk for hospital re-admission for patients achieving this activity improvement threshold.

Table 1. *MCID estimates for number of steps per day in COPD patients. Reproduced from Demeyer et al., 2016.*

Method	**MCID calculation**	**MCID estimate (steps/day)**
SEM	$SD_{Baseline} \times \sqrt{(\mathbf{1} - ICC)}$	599
Empirical rule effect size	$0.08 \times 6 \times SD_{\Delta}$	1,029
Cohen's effect size	$0.5 \times SD_{\Delta}$	1,072
0.5 × SD	$0.5 \times SD_{Baseline}$	1,131

3.2.3 Anchor-based methods

Anchor-based methods compare endpoint measures obtained using the new technology to an anchor that is itself interpretable in having known relevance to patients (Brożek et al., 2006). Anchors must be simple and measure a concept that is directly associated with the outcome measure under evaluation. In addition, when designing a study to estimate meaningful change it will be important to select an intervention and time period for which a change in the anchor measure is expected. It is possible that anchors may be objective measures using other related instrumented approaches, or they may be based on subjective assessments made by the patient or clinician. For example, if we wish to determine the meaningful change in an outcome measure of dexterity, collected using a tapping test delivered using an mHealth application on a smartphone, an objective anchor measure may be the count of finger to thumb taps achieved in a 30 second interval during an in-clinic performance test. Subjective anchors, on the other hand, might be a clinician-rating using the 0 to 4 scale for finger tapping assessment in the Unified Parkinson's Disease Rating Scale (UPDRS), or a global patient impression of change score where the patient is asked to rate any perceived change in bradykinesia (slowness of movement). To be applicable, meaningful change in the anchor measure must be understood, and changes observed in the anchor measure must be at least moderately associated with changes in the new outcome measure. This association may be assessed by Pearson or Spearman correlations, or more simply via visual inspection of trends. Because associations are typically modest, and anchors may be measuring slightly different concepts, researchers typically include a range of anchor measures to enable a range or consensus value to be derived.

Anchor-based methods can be used to define MCID for group mean changes or individual responder definitions. As the interpretability of the anchor is known, it is possible to define an anchor value, or range of anchor values, that represent the minimally important group mean change or an individual change indicative of a responder. In each case, by collecting both the new outcome measure and the anchor values in a suitable intervention study in which change is expected, the corresponding MCID and responder definition of the target outcome measure can be estimated.

When determining the MCID using anchor-based methods it is usual to define a value, or a range of values, for the anchor measure that correspond to the MCID and then calculate the target score that corresponds to that value (Brożek et al., 2006). A good example is reported by Motl et al. (2013). In their study, patients with multiple sclerosis were provided with a wearable accelerometer to measure daily steps over a 7-day period. The study included a number of subjective patient-reported outcome measures as anchor measures including the Multiple Sclerosis Walking Scale (MSWS-12) and the Patient-Determined Disease Steps (PDDS) scale. Meaningful change in both measures is well understood. A 10-point change in the total score of the MSWS-12 instrument and a 1-point change in the PDDS are considered to be the smallest changes deemed meaningful to the patient. Relating changes in steps/day observed to the anchor values collected, the authors reported MCID estimates of 642 and 915 steps/day for the two anchor comparisons respectively. Figure 1 presents the anchor-based MCID assessment resulting from the MWSW-12 analysis. While a trend is evident, this is a good illustration of the need for multiple anchors to be examined in the same study to enable the MCID to be triangulated – as the between-subject variability in the relationship between the anchor and the new measure is often high, as in this cae.

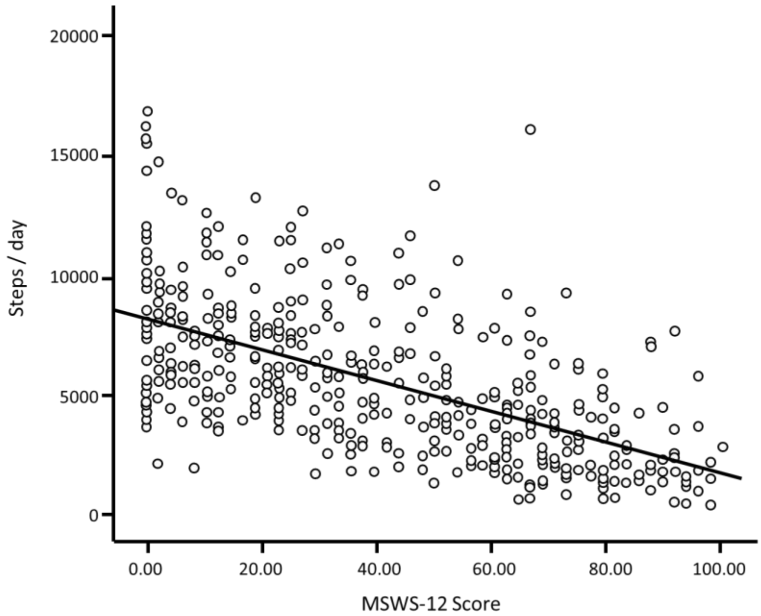

Figure 1. *Association between anchor measure (MSWS-12 score) and endpoint derived from wearable device (steps/day). This chart was redrawn from Motl et al. 2013.*

The most common approach to determine an individual responder definition is to classify responders based upon the anchor definition, and then use receiver operating characteristic curves to determine the optimal cut-off point for the target measure to define a responder, based on minimizing responder misclassification (see Ward et al. (2000), and Deyo and Centor (1986), for example).

It is acknowledged that in some cases suitable anchor measures cannot be determined. For example, despite attempting to derive the MCID for total daily steps in COPD patients from anchors based on the 6-minute walking test distance and Chronic Respiratory Disease Questionnaire (CRDQ) scores, Demeyer et al. (2016) reported that this was not possible in their evaluation as these measures were found to be only poorly correlated with the total daily steps measurements. In this case, they relied upon distribution-based methods to evaluate the MCID.

4. INCORPORATION WITHIN PRODUCT DEVELOPMENT

Defining meaningful change should be a component of development activities when creating applications using immersive, interactive and mHealth technologies to assess clinical outcomes in clinical research. In addition, defining pertinent clinical outcomes that can be automatically calculated during the use of rehabilitation applications, and their associated values of meaningful change, should be a component of the development and testing of rehabilitation applications. For example, when developing an application to assist patients in the correct and regular conduct of a rehabilitation exercise regimen, technologies such as Microsoft Kinect also enable the accurate tracking of joint coordinates and movements which can be the basis of objective outcome measures defining, for example, joint ranges of motion. These outcome measures can be used to define clinical endpoints that can be tracked over time, and the MCID or responder definition of these new endpoints should be understood.

Studies to assess the use of these technologies should include the incorporation of relevant anchor measures. This has the benefit of providing an additional demonstration of intervention effect in addition to providing the means to assess meaningful change in the outcomes derived from the new technology, in the ways described above.

Where it is difficult to determine suitable anchor measures, the use of a patient global impression of change scale might be sensible. This scale, often used in pharmaceutical clinical trials, enables the patient to assess whether aspects of their condition have changed to a degree that is meaningful to them, in comparison to their state at baseline (Figure 2).

Since the start of the study, my overall status is:

1: Very Much Improved
2: Much Improved
3: Minimally Improved
4: No Change
5: Minimally Worse
6: Much Worse
7: Very Much Worse

Figure 2. *The Patient Global Impression of Change patient-reported outcome measure*

This methodology will enable greater understanding of the value and interpretation of new and novel endpoints derived from new technologies, and provide interpretation to effect sizes observed during rehabilitation application assessment.

5. CONCLUSIONS

Meaningful change determination is an essential component of clinical endpoint development. mHealth, immersive and interactive technologies offer great potential in the development of novel clinical endpoints that may provide important insights into the assessment and monitoring of health status. This includes applications developed to measure health status, in addition to those intended as interventions where any resulting longitudinal changes may also be measured while using the technology application. However, the literature contains very few examples of the estimation of meaningful change associated with endpoints derived from mHealth and interactive technologies, making the interpretability of the impact of interventions measured using these technologies problematic. The approaches summarized in this paper, however, are strongly recommended to be implemented alongside application development. This can be facilitated by early planning to include anchor measures within pilot and validation studies to ensure the utility of new clinical technology applications intended to measure clinical change, and solutions developed as interventions to generate important changes in health status.

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Virtual cubes in 3D or 2D for persons with Parkinson's disease?

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ABSTRACT

A pilot study with the "10cubes" for small and precise movements and training in the virtual environment was carried out. 13 persons with Parkinson's disease participated in the study. Such activities can increase participation, slow down the progress of the disease and contribute to the functional improvements of the hand that lead to the increased quality of life.

The movement of the hand was assessed with a small 3D camera, also suitable for the estimation of kinematic parameters. We have performed a study with a small group of participants that were randomized into 2 groups; one group using an LCD screen and the other using 3D goggles (Oculus Rift CV1) enabling to follow the task in virtual environment. Both groups took 10 training sessions within 2 weeks. Their task was to collect 10 virtual cubes one-by-one and put them in the virtual treasure box. Clinical tests (Box and Blocks Test and motor part of the UPDRS) were carried out in the clinical settings prior and after the training sessions. We hypothesized that the different feedback equipment may provide different results, but found no statistically significant differences in clinical tests in the rather small group of participants. Additionally a kinematic estimation of the functional performance was tested.

1. INTRODUCTION

Parkinson's disease (PD) is a slowly progressive degenerative disease of the extrapyramidal system with unknown cause. Often begins in adulthood at the age between 35 and 60 years. Men become ill more likely than women (Wooten et al. 2004). Often the clinical features of the PD are rigidity (muscle stiffness), bradykinesia (slowness of movement), tremor and postural disorders. PD typically affects the patient's daily activities, its functioning, participation and quality of life in all stages of the disease and at different ages of patients. Currently degeneration of dopaminergic neurons that triggers changes in the basal ganglia network (Melnik, 2014) is mainly treated by levodopa/dopamine agonist. However, this may cause that the patients become less responsive to the medication over time. Additionally, physiotherapy has become more and more important in individuals with PD as people with PD retain more than 3/4 of all activities (Duncan and Earhart 2011, Janković 2008). Balance, posture or upper extremity functions often impact the quality of life; especially mobility related functions and is highly related to participation.

Physiotherapy increases participation and contributes to the quality of movement, physical capacity and manual activities; balance, walking, reaching, grasping, etc. Recently exercise based computer games (Barry et al 2014) have been introduced as a rehabilitation tool to the people with PD and this field is rapidly developing. There have been several reports on functional progress and performance, but less research was dedicated to safety and clinical benefits. Most of the reports applied commercial games (Nintendo Wii or Kinect Xbox) which were often found too fast and too complex (Barry et al 2014) . However, a feasibility study taking into consideration safety and functional outcomes (balance, dynamic gait and quality of life) when using commercial outfit of Kinect AdventuresTM reported on positive outcomes (Pompeu et al 2014). Some authors also reported on positive effects of computerized cognitive training in persons with PD [8] or positive cognitive effect when using video games (Torres 2008). Nowadays, most of the studies have been dedicated to mobility, balance and large range of motion movements. This is perhaps due to the inability of commercially available "exergames" and equipment (Kinect) to assess small scale movements. For small range of motion movement like reaching and grasping so far only limited equipment was available (CyberGlove Systems LLC and similar), while the resolution and ability to track motion with the optical Kinect like systems was not sufficient. However, grasping and fine finger motion may present an important task for persons with PD and may significantly contribute to the improvement of their quality of life.

Therefore we have developed a grab and grasp training program for small movements (Cikajlo et al, 2016) for persons with mild neurolomuscular impairments. To the best of our knowledge there is only little information available on virtual reality supported hand and finger skills and coordination training in Parkinson's disease, but the raising virtual reality technology offers promising results (Wang et al 2011, Miller et al 2014). We hypothesized that the choice of different displays for following the virtual task may affect clinical outcomes.

2. METHODOLOGY

2.1 Equipment

Virtual environment (VE) for pinch and grip was created in Unity3D (Unity Technologies, CA, USA). The dedicated space with simulated grass floor was limited with hidden walls and a model of a treasure box. In the middle of the dedicated space 10 cubes with the same physical model, size, virtual weight, bounce stiffness, material, etc, were placed. The goal of the task was to grab and put all the cubes, one-by-one with the virtual hand into the treasure box. The virtual hand was a VR avatar presentation of the participant's hand that was tracked in real-time by the mini camera (Leap Motion Controller, Leap Motion Inc., CA, USA). The camera tracked hand and fingers position, both required for construction of the 3D VR hand motion (Fig. 1) and the participant can view his/her hand in the VE. We designed an environment for left and right handed participants; the right handed grabbed the cube with the right hand and put it in the box on the left side of the VE and vice-versa for the left handed participants. The software for the assessment and control was written in C# using Leap Motion libraries. We designed the VE for the use with LCD screen/laptop and with the 3D goggles (Oculus Rift CV1, Oculus VR, LCC, USA).

Figure 1. *LEFT: Left handed participant practising pinch and place cubes in 3D VE (Oculus Rift CV1). The hand motion is tracked by the small camera on the table. RIGHT: Right handed participant is practising the task on the 15.2" laptop.*

2.2 Subjects

In the study so far 13 persons with Parkinson's disease participated. All participants were patients of the rehabilitation hospital and were included in the study according to the inclusion criteria: 1. Parkinson's disease diagnosis, 2. minor problems with daily activities and upper extremities, 3. Hoehn and Yahr Scale level 2-3. The participants were randomized into 2 groups; a group 1 (mean age 67.5 years, 2 men, 4 women, 4 with right hand affected and 2 with left hand affected) performing tasks with LCD/laptop and a group 2 (mean age 68.4 years, 3 men, 4 women, 7 with right hand affected and none with left hand affected) using 3D goggles.

The study was approved by the ethics committee of the University rehabilitation institute, Republic of Slovenia and each participant provided a written content.

2.3 Assessment protocol

The participants were randomized into 2 groups by draw. The 1st group of participants practised grab and grasp in VE on the laptop computer and the 2nd group participated performed almost a similar task in 3D VE using Oculus Rift CV1.The participants were seated in a comfortable chair in front of the screen (2nd group with head mounted 3D display). They raised their more affected (if both upper extremities were affected equally, then the dominant hand) hand above the small camera placed on the table below the hand. The camera was able to track the hand and finger movements in real-time and communicated with the computer through the USB port. The participant grabbed any of the virtual cubes lying around the VE and put it in the treasure box. When the virtual cube fall into the treasure box it disappeared and the participant scored. One virtual cube by one until the last 10th cube or until the 120s of foreseen time elapsed. The virtual cubes were randomly spread in the VE and had all the same virtual size, weight, material, bouncing factor, etc, but different colour through the entire protocol. If the participant is left handed, the treasure box would be mirrored to the right side of the screen. However, if the participant had pushed the virtual cube in the floor, the cube would have disappeared without a score for the participant and that cube was lost.

Each of the participating subjects took 10 consecutive training sessions in 2 weeks, each session lasting for max 30 min. Within one session the participant took 5 trials. Each trial lasted 120s, unless the participant finished the task earlier by putting all 10 virtual cubes successfully in the treasure box. A short break of 1-2 min was taken between two trials.

A day or two before the training sessions the participant entering the program took clinical tests Unified Parkinson's disease rating scale (UPDRS III) motor function part III (Movement Disorder Society, 2003) and Box & Blocks (BBT) Test (Fisher, 2003). Both tests were carried out within the clinical environment by a certified occupational therapist. The same clinical tests were carried out immediately after the 10 training sessions.

2.4 Data analysis

Primarily the outcomes of clinical tests UPDRS III and BBT were analysed. Data assessed in each participant before and after the training sessions were statistically analysed using Matlab statistical toolbox (Mathworks Inc., MA, USA). Data were tested for skewness and kurtosis. If the skewness was between -0.5 and 0.5, data would be considered symmetrical. If also kurtosis was close to 0, data would have been considered normally distributed. In the opposite case, we would apply non-parametric Wilcoxon test.

We have examined whether there was any significant change ($p < 0.05$) after the training sessions in clinical terms. An analysis for affected and non-affected hand was carried out for both groups of participating subjects separately.

Additionally, we carried out analysis of hand kinematics, focusing on successfulness in virtual cubes manipulation, speed of manipulation, distance covered, and number of trials. These values were calculated from measured data (tracking global coordinates of each segment of the finger, and hand). Each manipulation of the virtual cube was presented with different colour.

3. RESULTS

The participants managed to achieve higher BBT score (how many cubes in 60s of time) after the virtual task sessions. In average their score increased from 46 SD 5 to 49 SD 6 for the affected hand and from 49 SD 3 to 51 SD 5 for the non-affected hand in the LCD group (Fig. 2). The skewness of the affected hand data was below - 0.5, and the Wilcoxon non-parametric test demonstrated statistically non-significant changes ($p = 0.293$, $Z = -1.05$), 4 persons improving their score and 2 participants' scores were lower than prior to the training sessions. Similar outcomes were found with non-affected hand ($p = 0.292$, $Z = -1.05$), 5 participants improving their score and 1 performed worse than prior to the training sessions.

The 3D group performed similarly; they improved their affected hand score from 50 SD 9 to 51 SD 10 and non-affected from 53 SD 5 to 54 SD 6 (Fig. 2). The changes were indeed statistically non-significant ($p = 0.67$, $Z = -0.43$); 4 participants improved their score for affected hand and 3 did not. For the non-affected hand we found improvements of score in 4 participants, no changes in 2 and 1 participant performed worse than before the training sessions.

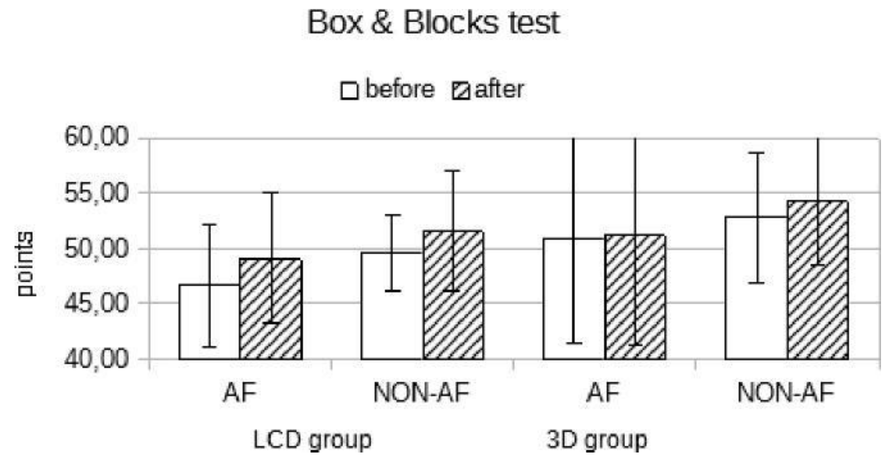

Figure 2. The mean BBT *score improved (more boxes collected, more points) for both groups of participants for affected and non-affected hand. However, the LCD group demonstrated larger score differences before and after the training sessions than the 3D group.*

The changes in the motor part of the UPDRS (part III) were marginally statistically significant ($p = 0.06$, $Z = - 1.84$) in both groups. The mean score demonstrated improvements (lower score) in both groups (Fig. 3), larger in the LCD group; in both groups 4 participants improved their UPDRS III score (lower score), but none of the participants were worse than prior to the training. There were no changes in 2 participants in the LCD group and 3 participants in the 3D group. However, the LCD group had significantly higher score and larger standard deviation prior to the training sessions.

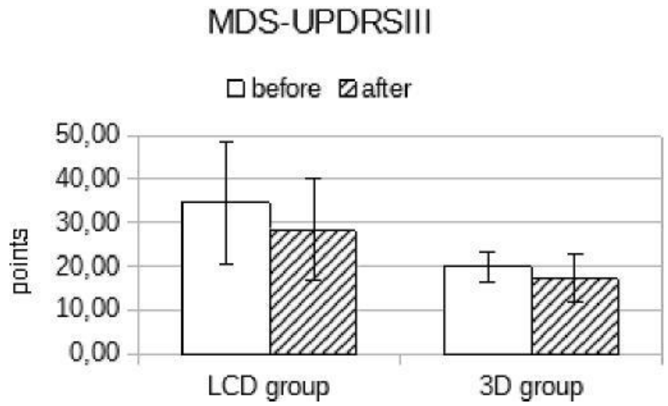

Figure 3. *Motor part (III) of the UPDRS demonstrated improvements in both groups (p = 0.06). The improvement (lower UPDRS score) was more prominent in the LCD group, but obviously this group had different starting point and high standard deviation.*

Kinematic differences between the non-affected dominant hand (young healthy reference subject) and affected hand of the participant with Parkinson’s disease are presented at Figure 4. The virtual cube rarely dropped out of the healthy subject’s hand before ending up in the treasure box. However, this was often the case for participants with Parkinson’s disease. They returned, grabbed the same or the other virtual cube and continued with the task. Besides, their grabbing and grasping strategy was also different in terms of speed and movement direction.

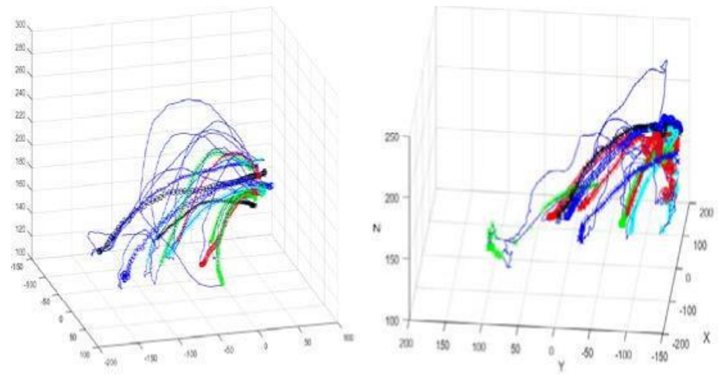

Figure 4. *LEFT: kinematic trajectories of the non-affected hand at pick & placing the virtual cube from the VE to the treasure box on the right. RIGHT: kinematic trajectories of the affected hand of the participant with Parkinson's disease. One may notice that several virtual cubes were grabbed more than once.*

The total time of manipulation of the virtual cube had significantly increased in the 4th session together with the manipulation time (Fig. 5). This was the period when the participants started to perform the task slower, but more precisely (less virtual cubes dropped out of hand). Consequently the number of successfully inserted virtual cubes to the treasure box had started to increase after the 5th session. At the 7th session the participants already managed to put 8 virtual cubes to the treasure box in 120s. From the 8th session the participants also speeded up the task performance, decreased the time of manipulation by being more precise and not dropping the virtual cubes out of the hand, but directly in the treasure box.

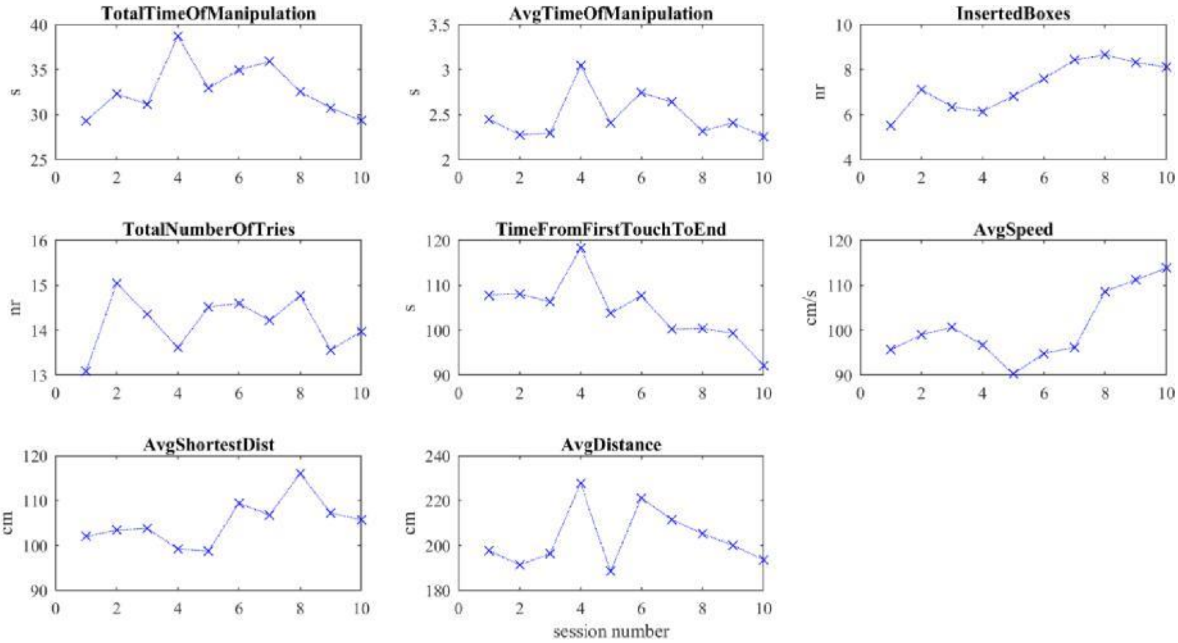

Figure 5. *Analysis of the virtual cubes manipulation: mean group values between the 4th and the 8th session demonstrate that the participants started more precise movements without losing the cubes on the way to the treasure box. Consequently they performed faster and more successfully (less trials, faster, more inserted boxes, shorter distance).*

4. DISCUSSION

The mean BBT practically demonstrated improvement for both groups; slightly more for the LCD group and less for the 3D group. At this point the results may be favourable for the LCD group. They did not need to put anything on their head, the exercises were a bit simpler and the outcomes were even better. However, the better starting point in the LCD group should not be neglected and could be potentially overcome by a larger number of participants.

Both, the BBT and the 10cubes training sessions required complex motor coordination and therefore the statement that participants demonstrated functional progress requires larger group of participants. Eventually 4 out of 6 participants improved their score, and 2 (LCD group) or 3 (3D group) participants performed worse than before training session.

The outcomes demonstrated improvement of motor control and other related functionalities as found by the UPDRS motor examination. The changes were larger in the LCD group as their starting point was rather poorer; in average they achieved 15 points more on the UPDRS scale, which means they lack more motor control than the 3D group. However, the non-parametric statistical analysis showed that the changes were equal in both groups. Eventually 4 out of 6 participants improved their score, no significant changes were in 2 (LCD group) or 3 (3D group) participants, but none of the participants performed worse than before training session.

The kinematic analysis clearly shows that participants in average picked the following strategy; at the start tried to perform as fast as they could, but their failure rate was very high. They hardly managed to put 5 cubes into the treasure box; even the number of trials was larger. Then the participants performed much slower, but reliably and needed more time for manipulating the cubes. But they were more successful. Last 3 sessions clearly shows that escalation of average speed, less time for manipulation and simultaneously collecting more cubes or even finishing the task prematurely must have led to the improvement of motor coordination, especially if we consider that the medication plan did not change for any of the participants.

Clinical tests are well accepted and may demonstrate the actual progress, but complementary information on kinematics may play an important role in the future. Even if we had not confirmed the superiority of the 3D technology over 2D, we would assume that the virtual cube game have enormously increased motivation and thus the participation of the subjects. The main advantage of the 3D version over the 2D version may be a vision depth that plays an important role in reaching and grasping as well as the fact that patients were somehow isolated from the outer world by goggles and headphones. However, patients with poor spatial perception ability may prefer the 2D game. Therefore we suggest that the study shall include more participants and consider measuring the intrinsic motivation (Goršič et al, 2017). Such activities may also lead to the improvement of cognitive functions and consequently the quality of life of elderly (Toress, 2008) and people with Parkinson's disease.

5. CONCLUSIONS

In the preliminary study with only few participants with Parkinson's disease we cannot confirm any differences between the two applied approaches. Both groups performed well, improved their functional pick and place tasks in virtual environment and in the real environment as demonstrated by clinical tests.

Fused information from kinematics as presented in the figures using artificial intelligence (AI) techniques could provide meaningful information about the functional improvement of grabbing and grasping the objects. This may in combination with the clinical tests lead to the conclusions that functional improvement of the hand function had taken place.

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Why are educational robots not being used in Special Education schools despite proof that they are beneficial for their students?

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ABSTRACT

Previous interventions have proven that the use of robots in Special Education (SE) is beneficial for children, producing an increase in engagement and goal achievement. However, the use of robots rarely continues after the relevant study ends. In this paper we analyse previous studies that used robots in SE and interviews with SE teachers to obtain their views regarding reasons for lack of uptake of this technology. We propose a solution based on the use of a user-centred design approach for all components of the system, including methods of interaction, learning activities, and the most suitable type of robots.

1. INTRODUCTION

The first recorded use of robots as educational tools dates back to the 1980's, with a mechanical turtle used to teach Science, Technology, Engineering and Mathematics (STEM) subjects (Papert, 1983). However, the role of robots in education was first reviewed during the 1990's, with the first scientific publications highlighting the potential of this technology not only in STEM or Mainstream education, but also in Special Education and rehabilitation, mainly with a focus on children with Autism Spectrum Conditions (ASC) (Bühler, 1998; Cooper et al., 1999; Lees and Lepage, 1996). At the same time, LEGO started to market the Mindstorms robotic line in 1998, a system for inventing and building robots through a modular design and LEGO plastic bricks, that is still being manufactured and used up to date.

Nowadays, educational robots are mainly used in Mainstream Education (ME) to teach STEM subjects (Armesto et al., 2015; Virnes et al., 2008). However, the use of this technology acquires special importance in the field of Special Education (SE), where studies exploring the use of robotics with children with ASC and Learning Disabilities (LD) have shown that they can be used as an effective tool to increase engagement and, consequently, goal achievement, as well as to raise interest in a specific task or subject (Andruseac et al., 2015; Standen et al., 2014a, 2014c; Virnes et al., 2008). Robots used in studies with children with ASC and LD can be put into two main categories: humanoid robots and non-humanoid robots, and their prices range from around £100 to £10,000, although no price is available for some non-commercially available robots developed specifically for research studies. One of the earliest pilot studies on the use of robotics in Special Education (Karna-Lin et al., 2006), emphasised that this technology can help discover hidden skills of students with learning difficulties, with the potential to offer different ways of interaction and the versatility of fitting within different learning styles. However, despite the benefits that educational robots seem to offer, and the existence of studies that tested various robots in Special Education schools, these robots do not continue to be used after the relevant study ends. This raises an important question: why? The aims of the study presented in this paper are to answer this question establishing the main reasons for lack of uptake of this technology, as well as to introduce a suggested solution to the issues found. This solution is based on working very closely with the potential users of systems used to control educational robots from the early stages of the design to the final testing.

2. METHODS

In order to discover why educational robots are not widely used, we first conducted a review of previous research studies that have used robots with children with ASC or LD. The characteristics of these studies and the systems that they used were annotated, compared, and analysed, contrasting also with the researchers' previous experience using robots in Special Education schools (Aslam et al., 2016; Galvez Trigo and Brown, 2014; Hedgecock et al., 2014; Standen et al., 2014b, 2014c). For this analysis, we extracted information about the robot used and its type (humanoid or non-humanoid) and checked its commercial availability and price when relevant, the user group chosen, the control devices that were necessary to operate the robot, who was the person controlling it, the availability of an interface for the final users, and finally, the type of activities included during the study. The results of this analysis can be seen in Table 2 and enabled us to compare the different systems used based on those factors. Once these data were collated, a series of informal interviews were conducted with Special Education teachers in schools situated in Spain and the United Kingdom.

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2.1 Analysis of previous studies

Due to the changing nature of technology, especially robotics, we decided to focus our analysis on studies carried out from the year 2000 onwards, covering studies from different countries with participants with ASC or LD.

Several studies have been conducted, however, as some researchers highlight (Cho and Ahn, 2016; Pennisi et al., 2016), most of the research in this area focuses on the technical development and construction of these robots, and not on their actual testing in real-life settings. The studies reviewed have used different robots and different methods of interaction with the robots to try and see their effectiveness and effects when used with children with ASC and/or LD. Most of them reached similar conclusions, and although the conclusions were positive, none of the studies has had enough impact to get to the knowledge of SE schools and encourage them to acquire the piloted system, in those cases where the system was commercially available.

2.1.1 Eligibility criteria.

Since the purpose of this study was not to offer a systematic review of the studies that have used robots in Special Education, but to find out why educational robots are not used in the classroom, the following selection criteria was applied. Studies must have been carried out from 2000 onwards, they must include at least a pilot with children with ASC and/or LD, they should not present repetitions or variations of the same experiment with the same system, even in different years, and they must describe the robot and system used. Based on these criteria, we filtered the results obtained and analysed 18 studies that used educational robots in Special Education settings.

2.2 Interviews with teachers

After carrying out the review of the relevant systems, we contacted three Special Education schools in order to schedule a series of interviews with teachers to discuss the reasons why they believe educational robots are not being used in the classrooms. One of these schools had already worked with the research team in previous studies.

2.2.1 The participants.

The participants were teachers working in a school for children with ASC and/or LD. One of the schools was a Special Education school from Nottingham, UK, for children aged 3 to 19, whilst the other two were a state and an independent Special Education school in Toledo, Spain, both for children aged 3 to 21. We selected the three above mentioned schools for several reasons. Firstly, they are all SE schools, having students with high-functioning to low-functioning ASC, MLD, SLD, as well as PMLD that in some cases are accompanied by Physical Disabilities (PD) such as Cerebral Palsy (CP), covering this way a wider range of children with ASC and/or LD. Secondly, from our participation in various projects that used educational robots in SE, we have observed that there are cultural and organisational differences in the way Special Education is approached among different countries (Edurob, n.d.; MaTHiSiS, n.d.), and including participants from two different countries would enable us to obtain a broader perspective, as well as to see if despite the cultural and organisational differences, we would obtain the same conclusions. Lastly, we deemed it important that the participants felt comfortable during the interviews, therefore, conducting them in their native language was the best option, since a member of the research team is a native Spanish speaker we opted to approach schools in Spain. As in Spain there are usually significant differences between state schools and independent schools, we decided to recruit one on each category. In order to recruit participants, we approached the head teacher of each school and presented a summary of the proposed study. They circulated that information among their teachers and directed us to those that were interested in participating. A total of 13 teachers volunteered to participate in the interviews: 3 from the school in the UK, 7 from the state school in Spain, and 3 from the independent school in Spain. Participants came from different generations and backgrounds, with some having previously used robots in the classroom and some others not. Since the study was introduced to the teachers by their head teacher, it was not possible to determine the reasons why not all teachers volunteered to participate, and their personal interest on the use of these technologies in the classroom might have played an important role. However, head teachers indicated that the overall reaction to the study was very positive also among teachers that did not volunteer, and that they considered the participation high, given that most teachers had little time available. The school in the UK and the independent school in Spain had technologies such as iPads, computers, eye-trackers, and other assistive technologies. However, the state school in Spain only had computers available for some of the teachers and none for the students.

2.2.2 The interviews.

With the teachers in the UK, one-to-one interviews were organised, whilst, due to time and travel restrictions, two focus group interviews were held with the teachers from the schools in Spain. During the interviews, a first introduction to the topic and past and current research was given, as well as to the robots and systems that had been used, showing them pictures and explaining to them the main characteristics of those studies. This was followed by an informal questions & answers session where we directed them towards indicating why they believed that educational robots are not widely used in SE, and what would be their main reason for not using any of the systems that we presented them.

3. RESULTS

3.1 Analysis of previous studies

The most relevant results obtained from the analysis of previous studies can be classified into three main categories: the robots, the methods of interaction, and the educational activities.

3.1.1 The robots.

After the analysis, we found out that 6 out of 18 studies were conducted using non-commercially available robots that were built purposely for those research studies, and none of them have become commercially available to date, with another one using both a commercially and a non-commercially available robot (Billard et al., 2007; Jimenez et al., 2016; Kozima et al., 2005a; Lathan and Malley, 2001; Marti and Giusti, 2010; Robins et al., 2003; Wainer et al., 2014). These robots can be seen in Fig. 1. A major explanation regarding why those robots are not widely used in SE schools is that schools do not have access to them. Therefore, we will not elaborate further on these systems. Instead, the remainder of our review focuses on studies that used commercially available robots. Among these, the most used robot is the robot NAO (Aslam et al., 2016; Barakova et al., 2015; Lewis et al., 2016; Shamsuddin et al., 2012b; Standen et al., 2014c; Warren et al., 2015), a humanoid robot manufactured by Softbank Robotics that measures 58cm and offers 20-25 degrees of freedom (DoF), various sensors, and a toy-like appearance. One of the main drawbacks for use of NAO is its price, as it currently retails for a price of approximately £6,000, with retailers offering maintenance plans for extra money. For that price, a school needs to see a very high value-for-money and have the budget to decide to buy it. NAO has been used in 6 of the 12 studies that used commercially available robots, and it was most likely selected for education studies due to its friendly toy-like appearance, its capabilities, and its programmability. However, it is possible that marketing and publicity of the NAO robot, as it has been featured extensively in showcases, public events, and news reports, may have influenced interest in this specific robot type. Indeed, there are several other, more affordable robots that are very similar in appearance and features to NAO that have not been used in any published studies. Cheaper robots that have been used in other studies such as LEGO Mindstorms (a robotic kit that lets its user build a robot in different shapes and configurations using LEGO bricks, also with various sensors), used in 3 studies, and Sphero (a spherical robot that can be navigated and can produce sounds), used in 1 study, do not have as many features or capabilities as NAO. However, there is no evidence that they offer less benefits than the more expensive robots, and several studies featuring them have equally highlighted their potential in the field of SE (Golestan et al., 2017; Karna-Lin et al., 2006; Kozima et al., 2005b; Marti and Giusti, 2010), with a recent study comparing both types of robots finding little or no difference between their effectiveness and benefits (Aslam et al., 2016). The prices of the robots used in the studies analysed in this paper can be seen in Table 1. The reason why these robots are not widely used in SE yet may be because teachers do not see them as representing sufficient value-for-money. Some teachers might not know about the existence of some of them, and many might not know how to use them or will not have the time to spend in learning how to use them and creating activities for their students with them. The commercially available robots used in the analysed studies, Keepon, LEGO Mindstorms EV3MEG , R25 Milo, NAO, Sphero, and Topobo can be seen in Fig. 2.

3.1.2 Methods of interaction.

An important consideration for implementation of educational technology beyond the research study is: How and who controlled the robots during each study? If teachers, or teaching assistants, are not directly involved in the use of the technology during the research investigation, it can be very difficult – even impossible, for them to take up use of the technology without the support of the research and/or technical team. Analysis of the reported studies, showed that, in 12 of the 18 studies (Barakova et al., 2015; Billard et al., 2007; Jimenez et al., 2016; Kozima et al., 2005a, 2005b; Lathan and Malley, 2001; Lewis et al., 2016; Marti and Giusti, 2010; Robins et al., 2003; Shamsuddin et al., 2012b; Standen et al., 2014c; Warren et al., 2015), the robot was controlled using a Wizard-of-Oz approach, relying usually on a member of the research team to remotely control the actions and responses of the robot, normally without the knowledge of children who were interacting with it. The reason for this was, most likely, that control of the robot required a separate laptop interface and knowledge of the control interface/editor or programming language used, that is different for each robot. In many cases, teachers would not possess the skills and/or time needed to operate the robot. Lack of a user-friendly interface that teachers and children can use to interact with the robot can be a decisive factor when choosing if they should or should not buy a robot, as they must be able to use it in order to benefit from it. Additionally, robot sensors were not sufficiently sensitive or reliable to pick up a child's vocal response or gestures. This meant that a Wizard-of-Oz approach had to be used for some other studies thus limiting the teacher's ability to focus on other aspects of the interaction of the children with the robot, rather having to stay behind a computer controlling its actions. Apart from those considerations, 2 of the studies that did not use a Wizard-of-Oz approach did so because the activities consisted of building and programming the robot rather than controlling it and/or interacting with it. Another aspect to consider is that most studies focus on children with high-functioning ASC and/or Mild Learning Disabilities (MLD), and only 2 of those with Severe Learning Disabilities (SLD) or Profound and Multiple Learning Disabilities (PMLD)(Aslam et al., 2016; Standen et al., 2014c). Children in the latter two groups could have issues if they do not have an appropriate way of interacting with the robots that adapts to their needs. These ways of interaction might include the use of different Assistive Technologies (AT) such as micro-switches, joysticks, or different sensors that could interpret their orders. Only a few studies have used this kind of controlling devices, and this can be another reason why SE schools might have decided not to acquire one of these robots, since many students would not be able to benefit from them.

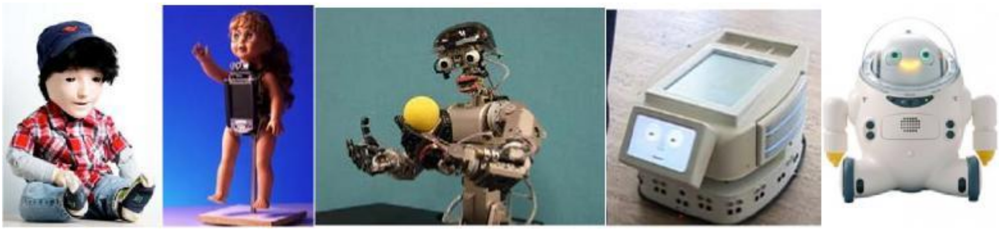

Figure 1. *Non-commercially available robots. From left to right: Kaspar* [University of Hertfordshire], *Robota* [EPLF], *Infanoid* [NiCT], *IROMEC* [IROMEC], *and ifbot* [Futaba]

Figure 2. *Commercially available robots. From left to right: Keepon* [CMU], *LEGO Mindtorms EV3MEG* [LEGO group], *R25 Milo* [RoboKind], *NAO robot* [SofBank Robotics], *Sphero* [Sphero], *and Topobo* [Topobo]

3.1.3 Educational activities.

The activities featured in the research studies analysed can also be seen in Table 2. Most studies used imitation games and prompts to motivate the children to initiate a social interaction with the robot (Billard et al., 2007; Golestan et al., 2017; Kozima et al., 2005a, 2005b; Lathan and Malley, 2001; Leo et al., 2015; Lewis et al., 2016; Robins et al., 2003; Shamsuddin et al., 2012b), however, these type of activities are more relevant for children with ASC than for children with LD, especially for those with SLD or PMLD. For these activities the children were generally able to interact independently with the robot, although supervised by a teacher, and with a researcher controlling the robot in most cases. Two of the studies involved building and programming a robot using a graphical interface (Karna-Lin et al., 2006; Virnes et al., 2008). This was reported as challenging and required more support from teachers, with some students indicating that they would prefer the use of a remote control or buttons to control the robot rather than having to program it on the given computer interface. Only a few studies included activities focused on helping the children develop other skills such as choice-making, cause and effect, or motor skills (Aslam et al., 2016; Standen et al., 2014c; Wainer et al., 2014). We believe that the lack of an appropriate and wide enough range of activities might be a decisive factor for schools and teachers when deciding whether acquiring a robot will offer sufficient value-for-money.

3.1.4 The teachers' views.

The results of the interviews were very consistent, with nearly all teachers showing great interest in the use of educational robots in their classrooms. Only one teacher from the independent school in Spain showed scepticism but agreed that interventions using educational robots may be beneficial for some students. Only two of the teachers, from the UK, were involved in studies using robots in the classroom in the past or had previous experience in using these kind of robots. Most teachers were only aware of the existence ofthose robots with a stronger marketing presence, such as NAO and the LEGO Mindstorms, or others that they had previously seen in toys or technology retailers, with almost none of them used in previous research studies.

Teachers highlighted five points as the main reasons why they would not use one of the systems discussed:

- *Price.* The price was considered the major concern and barrier for which their school would not acquire the technology. All 13 teachers highlighted that if the school has no budget for it, it will not matter how good it is and what a great value-for-money it offers.
- *Lack of a user-friendly interface.* The lack of a user-friendly interface that both teachers and students could use to interact with the robot was mentioned as the second most important factor, with all 13 teachers indicating this issue as an important one.

- *Lack of appropriate alternative ways of interaction for their students.* Another great concern for teachers was that some students could not benefit from the use of this technology if it does not offer compatibility with alternative assistive ways of interaction, such as micro-switches, or movement-trackers. This was highlighted at first by 7 of the 13 teachers (those working with children with SLD and PMLD), although in the group interviews all teachers agreed on this point after their colleagues mentioned it, raising the number of teachers considering it an issue to 11 out of 13 teachers.
- *Contents not being appropriate for their students.* All 13 teachers highlighted that the contents or activities that the robot could perform would play a decisive role on whether the robot is being used or not. Some teachers mentioned that they would like to be able to create their own activities in an easy way, even if it is choosing and making combinations from a predefined set.
- *Not being able to use different robots with the same controlling interface.* 6 teachers (1 from the UK, 1 from the independent school in Spain and 4 from the state school in Spain) indicated that it may be necessary to use different robots to benefit a wider range of students, since a humanoid or a vehicle-like robot may not be suitable for all of them. From that remark, they indicated that having to learn and possibly buy two different software systems for that purpose would be very time consuming and confusing.

Table 1. *Table of prices of commercially available robots used in analysed studies*

Robot	Manufacturer	Price
Keepon	BeatBots	$279.99 (~£200)
LEGO Mindstorms	LEGO	£299.99
R25 Milo	RoboKind	~$5,000 (~£3,600)
NAO	Softbank Robotics	~£6,000
Sphero	Sphero	£119.95
Topobo	Topobo Korea	$149 to $1,250 (~£107 to £900)

4. DISCUSSION AND CONCLUSIONS

The benefits of the use of educational robots in SE are evident from the studies analysed. The teachers interviewed confirmed that they agree and would like to be able to use these robots in the classroom. However, there are still several factors that prevent schools from acquiring robots and integrating them within their curriculum.

Not being able to access the relevant robot, either because it is not commercially available, or its price is too high, is one of the main factors for non-uptake that we observed from both the analysis of previous studies and the interviews with teachers. This, together with the lack of a user-friendly interface that teachers and children could use to control the robot are the two main reasons why educational robots may not be widely used in SE schools. We also learnt that the range of activities that robots performed is not enough, and that more flexibility in this regard is needed, as well as more varied means of interaction for those with SLD or PMLD. Furthermore, 6 teachers mentioned during the interviews that they would like to be able to use more than one robot with just one interface, as they could try to acquire different cheaper robots instead of an expensive one if they believed that this approach would offer benefits to a larger group of students.

We suggest addressing these issues with the involvement of the users from an early stage in the design of the systems used in studies that use educational robots in SE. This way, the use of very expensive robots that will never be commercialised or that do not meet the requirements of children with ASC or LD could be avoided.

Since teachers and parents are the ones that know these children best, we propose to embark with them and their children on the design of a system that uses educational robots in SE to try to produce a system that can be adopted by schools. This solution follows a study carried out by a member of the research team in 2014, were an interface to control NAO using tablets was developed, using feedback and design suggestions given by teachers during the design process with positive results (Galvez Trigo and Brown, 2014).

Table 2. *Comparison table with main characteristics of the analysed studies*

Study	Country	User group	Robot	Humanoid robot?	Commercially available robot?	Controlling devices for robot	Robot controlled by	Graphic User Interface available for users	Type of activities
(Lathan and Malley, 2001)	USA	PD,CP	GIR-T	No	No	Laptop	Researcher, children	No	Imitation, storytelling
(Robins et al., [illegible]	UK	ASC	Robota	Yes	No	Laptop	Researcher	No	Imitation
(Kozima et al., 2005a)	Japan	Mainstream	Infanoid	Yes	No	Laptop	Researcher. Automatic mode to fix attention	No	Prompting social interaction, joint attention
		ASC	Keepon	No	Yes				
(Kozima et al., 2005b)	Japan	ASC	Keepon	No	Yes	Laptop	Researcher. Automatic mode to fix attention	No	Emotion and attention exchange
(Karna-Lin et al., 2006)	Finland	MLD	LEGO Mindstorms	No	Yes	Laptop	Teacher , children	No	Building the robot, programming the robot
(Billard et al., 2007)	UK	Mainstream	Robota	Yes	No	Laptop	Researcher	No	Imitation
	France	ASC					Automatic imitation		
(Virnes et al., 2008)	Finland	ASC, Behavioural, Emotional and Social Difficulties (BESD)	LEGO Mindstorms	No	Yes	Laptop	Teacher , children	No	Building the robot, programming the robot
			Topobo			Remote			
(Marti and Giusti, 2010)	USA	ASC, MLD, PD	IROMEC	No	No	Laptop, switches on robot's body	Researcher	Yes: XML-based	Turn-taking, follow me
(Shamsuddin et al., 2012a)	Malaysia	ASC, MLD	NAO	Yes	Yes	Laptop	Researcher	Yes: Choregra p he	Prompting social interaction
(Standen et al., 2014c)	UK	ASC, PMLD	NAO	Yes	Yes	Laptop, joystick, micro-switches, smartphone	Researcher, children	Yes	Choice-making, response, speech, cause and effect, motor skills
(Wainer et al., 2014)	UK	ASC	KASPAR	Yes	No	-	Children	No	Collaboration
(Warren et al., 2015)	USA	ASC	NAO	Yes	Yes	Laptop	Researcher	Yes	Joint attention
(Barakova et al., 2015)	The Netherlands	ASC	NAO	Yes	Yes	Laptop	Researcher	Yes	Prompting to build LEGO
(Leo et al., 2015)	Italy	ASC	R25 Milo	Yes	Yes	Laptop	Children	No	Emotion imitation
(Jimenez et al., 2016)	Japan	Non-diagnosed ASC, LD	Ifbot	Yes	No	Laptop	Researcher	Yes	Storytelling
(Lewis et al., 2016)	USA	ASC, MLD	NAO	Yes	Yes	Laptop	Researcher	Yes	Attention, imitation, joint attention, turn-taking, initiative
(Aslam et al., 2016)	UK	ASC, PMLD	NAO	Yes	Yes	Tablet	Children	Yes	Directions, listening, choice-making, speech
			LEGO Mindstorms	No		Remote			
(Golestan et al., 2017)	Iran	ASC	Sphero	No	Yes	Smartphone, tablet	Children	Yes	Speech, prompting social interaction

Teachers and parents will be asked about aspects of the design such as the type of robots it should be compatible with, the control devices that it should work with, and the activities to be included. Children expressing willingness to participate, for which parental consent is also given, will be able to take part, giving us design suggestions and using the system during the different piloting stages. This study was also introduced to a local group of young adults with LD, and we will continue to present updates during this group's regular meetings and to use their advice to improve the system. In order to achieve this, and based on the fact that many teachers knew only the robots with a stronger marketing presence, or those that, although have not been used in studies, are sold in stores, we will not only consider robots used in previous studies, but other commercially available and affordable robots that teachers and parents identify as good candidates. The same will apply to control devices and activities.

Being able to develop a user-friendly system that can be used to control different robots in SE classrooms, would also enable fellow researchers to conduct larger and longer studies, with more reliable data obtained from a real-life setting rather than from a controlled experimental scenario.

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User-centred design of an active computer gaming system for strength and balance exercises in older adults

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ABSTRACT

Strength and balance exercises are recommended to offset the physical and cognitive decline associated with an increased risk of falls in older adults. Active computer gaming (ACG) may be a potentially safe and enjoyable way for older people to participate in exercise. Involving older adults in the development of a bespoke ACG system may optimise its usability and acceptability. This paper describes the user-centred design of a system iteratively developed to deliver strength and balance exercise in older adults and suitable for display on a flat screen or using an Oculus Rift virtual reality headset. User testing of a prototype of the system in n=9 older adults indicated the safety, usability and acceptability of the system, with a strong preference for the screen display reported by users. Findings were used to modify the ACG system.

1. INTRODUCTION

Within the ageing population, reduced participation in daily activities and a reduction in physical activity lead to deconditioning, impaired function and reduced independence. Physical and cognitive decline in older age is additionally associated with an increased risk of falls. It is estimated that approximately a third of adults aged 65 and over will fall each year, making falls the greatest cause for hospitalisation in older adults (Masud & Morris 2001; Finucane et al. 2014). Guidelines recommend strength and balance exercises, completed in standing, to reduce the risk of falling in this population (Campbell and Robertson 2007; National Institute for Health and Care Excellence 2013). It is estimated that up to 42% of falls can be prevented by well-designed exercise programmes, such as the Otago Exercise Programme (Sherrington et al. 2011) which is an individualised, home-based programme with strength and balance exercises that can be progressed in difficulty (Gardner et al. 2001).

Active computer gaming (ACG) is becoming recognised as a potentially safe and enjoyable way for older people to participate in exercise and activities that may otherwise be difficult (Bleakley et al. 2015). There is also potential for older adults to practice these exercises unsupervised at home. Findings from a systematic review and meta-analysis of 35 randomised controlled trials (Howes et al. 2017) indicated that ACG was a safe mode of exercise for older adults with positive effects on physical and cognitive health outcomes including balance. However, it was notable the lack of studies of people at risk of falling, with most ACG interventions conducted with healthy older adults (n=23/35, 66%) in a clinical environment with supervision. Additionally, most of the included studies investigated commercially available gaming systems (n=23/35, 66%), such as the Nintendo Wii and Xbox Kinect. However, as these games are developed for healthy adults, they do not always match the ability of older adults, or meet their therapeutic needs.

Technologies delivering fully-immersive virtual experiences, such as VR headsets, are becoming more accessible and affordable. These could provide older adults with a more immersive and realistic virtual environment (Lu and Mattiasson 2013; Howard 2017), potentially influencing their enjoyment and allowing them to experience activities that may not otherwise be possible. The use of VR headsets in healthcare has included the management of a number of types of conditions: physical, for example, upper limb rehabilitation post-stroke (Holmes et al. 2016); cognitive, for example, with Alzheimer's disease (García-Betances et al. 2015) and autistic spectrum disorder (Newbutt et al. 2017); psychological, for example, anxiety, phobias and eating disorders (Riva et al. 2016). Most of these conditions are suited to treatment in sitting. Some studies have recently explored the use of fully-immersive VR in standing, walking on the spot and treadmill walking in healthy participants (Nilsson et al. 2016; Yoo and Kay 2016). In a study investigating treadmill walking in a fully immersive VR environment, healthy older adults (n=11, mean age 66±3 years) were capable of using immersive VR with minimal adverse effects, although as expected were more dynamically unstable than thir younger counterparts (Kim et al. 2017). Research to date reports limited information on the usability and acceptability of immersive virtual reality in this population.

Bespoke ACG systems can be specifically designed to deliver tailored rehabilitation exercises, such as the Otago Exercise Programme, to meet the ability and needs of older adults. Input from end users early in the design

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and development phase of an ACG system is one way to optimise its usability and acceptability. Older adults face a variety of challenges when engaging with ACG technologies. One study described challenges related to physical changes, cognitive changes and self-efficacy; stating that many of these could be avoided by involving older adults in the design and testing of such systems (McLaughlin et al. 2012). User-centred design (UCD) is used in software development to optimise usability of a system as rapidly as possible; it includes task analysis, usability testing, observations and feedback from users (Fisk et al. 2009). There is limited information published in the area of UCD for the development of rehabilitative technologies delivering falls prevention exercises for older adults

Previous work has discussed UCD methods in the development of ACG systems for older adults. One previous research team conducted workshops with older people to discuss requirements, brainstorm and sketch ideas, followed by a games session giving older adults the opportunity to play an initial prototype (Uzor et al. 2012). Proffitt and Lange (2013) describe an iterative process involving an interdisciplinary team and stakeholders in the design and development of a system for falls prevention. This included focus groups to explore barriers and facilitators to engagement, iterative user testing of prototypes and semi structured interviews to explore user experience. More recently, a protocol for UCD for ACG for older adults has been suggested (Brox et al. 2017). This protocol includes: gathering requirements from the literature, background information on the population, discussions about their requirements and observations of their use with commercial games; an iterative design and implementation process influenced by user feedback during observations, structured and semi-structured interviews and discussions; and an evaluation phase, involving piloting of the final prototype with new participants (Brox et al. 2017).

The aim of this study was to employ user-centred design methods to develop an ACG system to deliver strength and balance exercises, for display using two viewing mediums. The aim of the user testing was and to explore its safety, usability and acceptability, and older adults' perceptions of the two viewing mediums, during user testing with older adults.

2. METHODS

The research outline for the development of the first prototype of this system is summarised in Figure 1; the first prototype was developed for viewing on flat screen (study condition A) and using an Oculus Rift virtual reality (VR) headset (study condition B). This study was approved by the Office for Research Ethics Committees Northern Ireland and two day care centres based in urban areas of the city agreed to participate.

2.1 Development of the ACG system

The design and development of the system was an iterative process involving an interdisciplinary team of clinicians and developers. Both managers of day centres for older people and service users were actively involved in the study from an early stage, influencing the study design and the development of the system. During the information gathering stage, meetings were conducted with managers of two Age NI day centres for older adults (Figure 1, PPI A). The information gathered provided an understanding of the service provided by the centres, including the number of days it operated, the daily routine and the activities provided. Day centre managers also shared information about their service users, including the number of service users in total and daily, their level of function and needs, and their activity preferences. Older adults were referred to the day centres due to physical or social needs, and attended between one and five days per week, depending on their needs. The users of both centres enjoyed playing a variety of games, such as boccia and quoits, and arm chair exercises; one of the centres had purchased a Nintendo Wii, however, this was never used by any of the users as the staff were not familiar with its use.

Service users were involved at two points in the design and development process. Service users (n=25) were consulted during the early stages of development (Figure 1, PPI B). During three scoping meetings, they were shown images and given information about the technology and its potential for a falls prevention intervention, and given the opportunity to provide feedback. Handwritten notes were made on their questions, views, concerns and recommendations. Feedback was generally positive, with the service users showing interest in the novel technology. They described seeing family members play such games, and one stated they had seen VR headsets used in a TV programme. Many said they would be willing to participate, but that they would not be willing and/or able to travel to the university to take part. The outcomes of the meetings led to the decision to conduct the testing within the day centres rather than in the University Research Centre.

Later in the development process, when an initial prototype was available, two meetings were conducted with service users (n=18) to discuss the game design and choice of exercises (Figure 1, PPI C). During small workshop style meetings, older adults were given information about the ACG system and asked to provide feedback in order to refine the system. Many of the service users spoke about arthritis and osteoporosis as barriers to exercise, sometimes referring to having a good side and a bad side, and that their ability to complete the exercises would differ left/right accordingly. The service users, for the most part, thought that the other exercises seemed easier, and some stated that they completed similar exercises at home, prescribed by physiotherapists for hip or knee pain or following orthopaedic surgery.

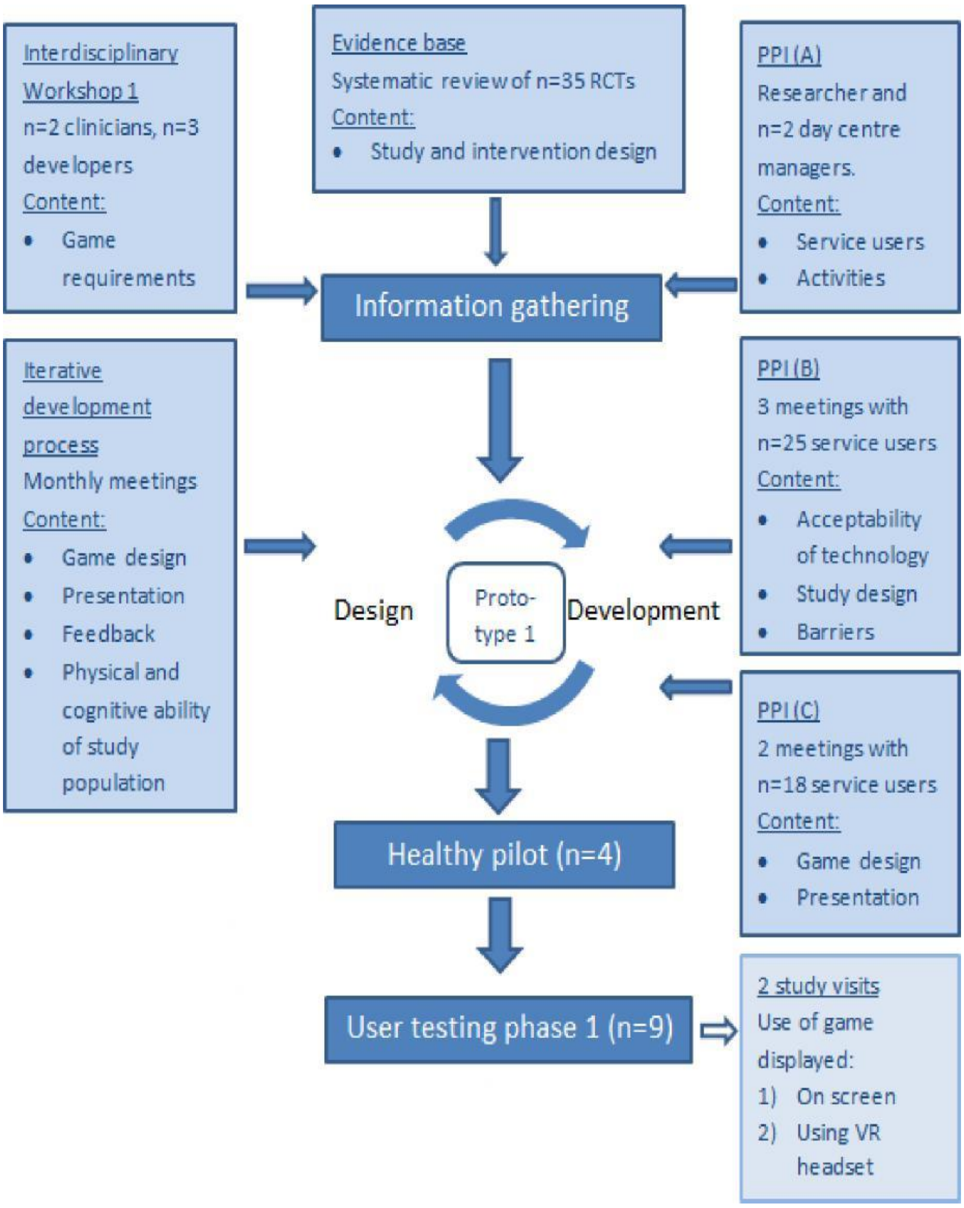

Figure 1. *Research outline*
(PPI – patient and public involvement, stakeholders and service users were consulted in the development of the ACG system)

Many expressed that they would prefer completing the exercises with a chair for support, to improve their confidence in performing the exercises. Most of the service users seemed very interested and keen to try the games, while some of the service users asked if they could try the game now, or said they would stand up to see if they could do the individual exercises. This provided a good indication that they may be willing to take part in the user testing when it commenced. During these meetings, the service users were also consulted about the presentation of the game. Images of screen grabs from the game were shown to the users in small groups of 2-3, and they were given the opportunity to provide feedback on their perceptions of the game design, colours, clarity and ease of reading of the text. This included use of colour and ease of reading. Day centre service users all stated that they could read the instructions and print within the games easily. They felt that all the colours were easy to see and read. Several service users reported that they thought the font size used on the score sheet at the end was too small and that too much information was presented. Comments and suggestions were fed back to the research team and implemented as appropriate.

2.2 Description of the ACG system

The VR content, based on the exercises in the Otago Exercise Programme, was developed using Unity 3D software (Unity Technologies SF Inc., San Fransisco, CA, USA). The software ran on an Alienware PC (Alienware Corps., Miami, FL, USA.) connected to a Microsoft Kinect Camera (Microsoft Corps. Redmond, WA, USA.) mounted on a tripod positioned at 85cm above desk height, to track user movements. The VR content was developed for display using the two viewing mediums, a 21inch monitor (screen condition A) and the Oculus Rift head-mounted display (Oculus VR., Irvine, CA. USA.; VR condition B). The purpose of this was to explore older adults' perceptions of the two viewing mediums.

The exercises in the Otago Exercise Programme were shared with the development team and the technical difficulty of developing a game that included these exercises was discussed. The ACG system included four mini-games to deliver exercise tasks based on four exercises included in the Otago Exercise Programme (Province et al. 1995): Knee Bends, the user bends their knees to duck under passing logs (n=10); Leg Abduction, the user raises their leg to strike balls positioned to the side (n=10 each side); Sideways Walking, the user steps to the side to avoid oncoming walls (n=10); One Leg Stand, the user stands on one leg to avoid rising water (3 x 10 seconds each leg) (Figure 2). In each mini-game, the Kinect camera tracked the participant displaying their bodily movements on the screen as a white figure. At the beginning of each game, the participant was instructed to stand on the yellow "X" to allow for calibration; the Kinect used this position as a reference point to track users' movements and success in each task. Additionally, prior to beginning the Knee Bends game, the height of the logs was calibrated to the height of the participant. The ACG system developed for display on two viewing mediums - on a flat screen and with an Oculus Rift VR headset.

As per feedback provided during the meetings with older adults, the system was developed to be able to detect the movements of the user with a zimmer frame placed in front to enable participants to use their own walking aid for hand support where required. The purpose of this was threefold: to improve participants' confidence, as falls efficacy scores indicated that most participants had high concern about falling; to enable them to play despite physical limitations, and it was expected that some may have low exercise tolerance due to de-conditioning; and, to ensure safety, so that participants could reach for hand support should they lose their balance.

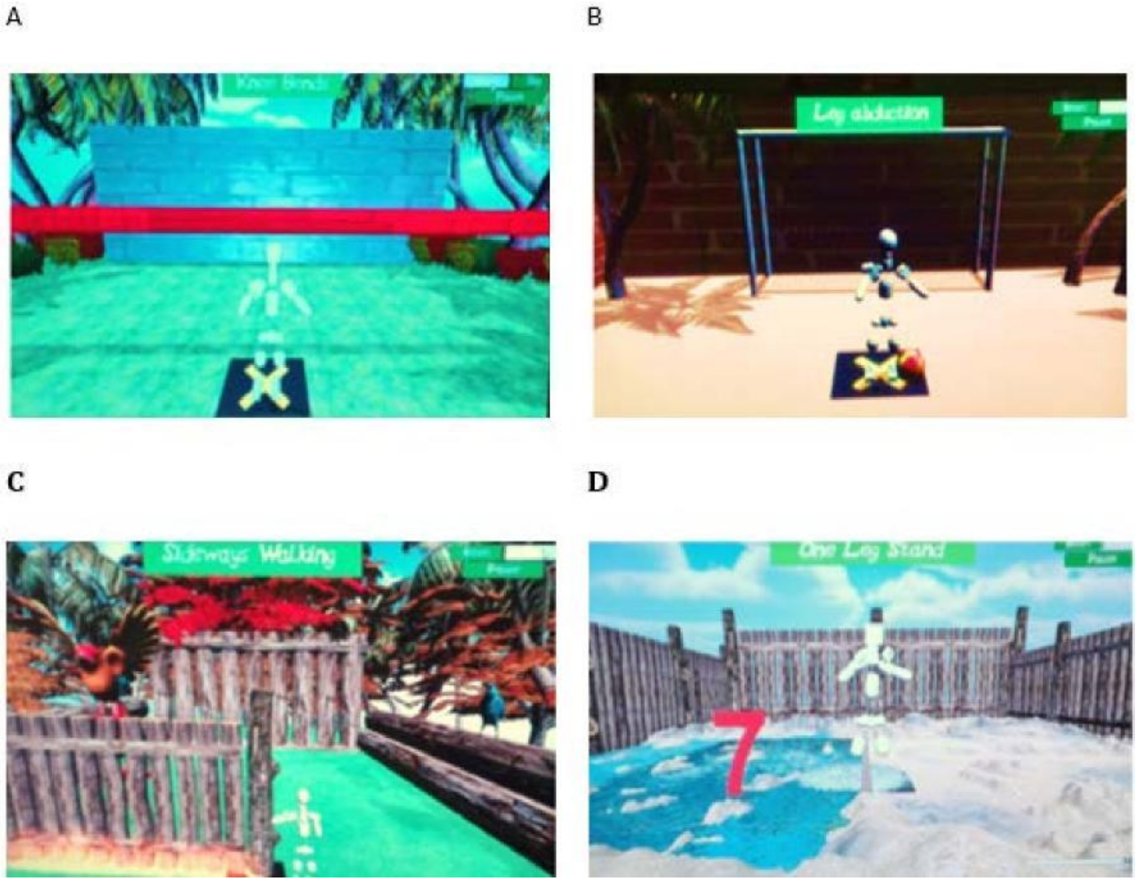

Figure 2. *Images of the ACG system*
A- Knee Bends; B- Leg Abduction; C- Sideways Walking; D- One Leg Stand

2.3 *User testing methods*
Participants were recruited through the two Age NI day centres. The study was carried out over one (screen condition only) or two visits (screen and VR conditions); and conducted in the day centre that the participant attended. Individuals were eligible for inclusion if they were aged over 65 years, had stable health. and were independently mobile with or without a walking aid. The eligibility criteria were chosen to be as inclusive as possible; however, as the exercises required to play the game were in standing, it was necessary to exclude older adults that were not

independently mobile such that they were bed or wheel chair bound. Older adults with a current acute or uncontrolled medical condition or significant cognitive impairment were excluded.

2.3.1 Procedure

Two researchers were present throughout testing. One researcher demonstrated the use of the system and mini-games, while the other highlighted key features of use and gave the participant the opportunity to ask any questions. Participants were advised to ask for any verbal or physical assistance that they may require at any stage, and to make comment with regards to their ability to complete each task and difficulty experienced doing so. Sessions were video recorded to supplement hand-written notes made during participants' use of the system.

The protocol had outlined a plan for randomisation of the order that study conditions were presented to the users. However, following piloting the VR condition in healthy adults, it was decided to introduce the system to older adults using the screen display for familiarisation prior to using the VR headset display.

2.3.2 Outcomes of interest

Safety: A safety checklist pro-forma was completed for each participant, to document both safety components and practical aspects of using the equipment during participants' use of the system.

Usability: Details of additional verbal and physical assistance required, as well as any participant comments were recorded on the safety pro-forma. The System Usability Scale (SUS), a reliable and valid measure of perceived usability (Brooke 1996), was completed by participants after each study condition. This scale comprises 10 items which are rated on a 5-point Likert scale ranging from 1 "strongly disagree" to 5 "strongly agree" to subjectively evaluate their perceptions of the ease of use and usability of the system. Scores above 70 indicate acceptable usability, while scores below 50 indicate unacceptably low usability (Bangor et al. 2008).
Comparison of usability scores for each study condition were used to compare older adults' perceptions if the two viewing mediums.

Acceptability: Acceptability was measured using the Attitudes to Falls-Related Interventions Scale (AFRIS). The scale includes 6 items which are rated on a 7-point Likert scale ranging from1 "strongly disagree" to 7 "strongly agree". The AFRIS items consider the following components of acceptability: attitudes; subjective norm; perceived behavioural control; identity; and, intention (Yardley & Donovan-Hall 2006 & 2007). Responses to the individual items of the AFRIS and any comments made by participants were explored in a semi-structured interview, recorded after the practical aspect.

Acceptability was also explored via a semi-structured interview. Interview questions were developed based on the aims of the semi-structured interviews, which included: to explore user experience and views on using the equipment; whether they found it useful and enjoyable; to identify any concerns; to explore appropriate usage time and setting; and, to gain understanding into barriers and facilitators to future participation. Semi-structured interviews lasted approximately 10 minutes, depending on the amount of information shared by the participant.

Initial assessment: On study visit 1, prior to use of the game, demographic information was collected including participant age, gender, falls in the last 12 months, walking aid use and number of medications. Assessments of physical function (Short Physical Performance Battery; Guralnik et al. 1994), balance (Berg Balance Scale; Berg et al. 1995), fear of falling (Falls Efficacy Scale-International; Yardley et al. 2005) and mood (Geriatric Depression Scale-15 item; Brown et al. 2005) were also collected.

2.4 Results

Nine participants (5 female/ 4 male) were involved in user testing of prototype 1; their mean (SD) age was 82.2 (6.3) years. Many participants used a walking aid at home (n=5) or when outside their home (n=7). Six out of nine reported having fallen at least once in the last 12 months; none of these resulted in injury. Four participants had a high risk of falling (Berg Balance Scale score <40), only one participant was considered to have high physical functioning (Short Physical Performance Battery score >10), and all participants had high fear of falling (Falls Efficacy Scale-International >28). All participants (n=9) completed a single use of the VR game displayed on screen, while n=4 completed an additional single use of the VR game displayed using a VR headset. Results are summarised in Table 1.

Table 1. *Summary of user testing of prototype 1*

Outcome	Screen display (n=9)	VR headset display (n=4)
Completion rate	82.9%	62.5%
Hand support	79%	100%
Additional instruction	72%	80%
SUS	70 (good)	52.5 (marginally low)
AFRIS	35.5/42 (acceptable)	n/a

Safety and usability: There were no adverse events during use of the system with either viewing medium; however, close supervision was required to ensure safety for both study conditions, particularly during the VR headset study condition. Participants often required the use of hand support and additional instruction during use of the system, this was slightly higher with the VR headset display study condition.

Usability and acceptability: Attitudes to the system were generally positive, and participants' SUS scores indicated acceptable usability of the screen display, but marginally low usability of the VR headset display (Table 1; Figure 3).

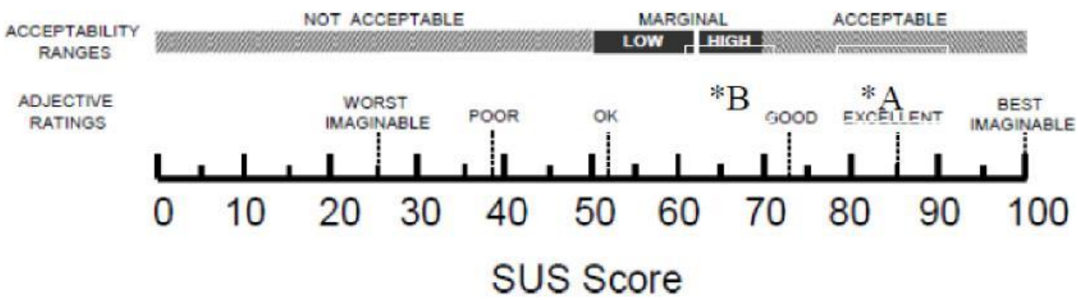

Figure 3. *SUS scores for study conditions indicated by *. Acceptability ranges and adjective ratings provide additional interpretation of SUS scores.*

Qualitative findings: Preference of the screen version was also evident in the semi-structured interviews, conducted with participants following use of the system. Overall results from the semi-structured interviews and comments recorded during use of the system suggested that the participants viewed the VR game, particularly when displayed on screen, as an acceptable mode of exercise; they found the game enjoyable and useful. However, they reported feeling disorientated with the VR headset. Nonetheless, they reported willingness to use the system in the future, confidence in their ability to do so and a preference for use within the day care setting rather than at home. Participants' attitudes to the ACG system were influenced by several factors which were categorised, using an inductive content analysis approach, into three over-arching themes: User experience; motivation; and, ability to participate (Table 2).

Table 2. Examples of qualitative themes

Theme	Examples
User experience	"All in all I was very happy with the system... It was presented well and I enjoyed it actually... Admittedly I did get a bit tired at the end there but I thought it was quite good" (77 years, male) "with the headset the movement was throwing me off a bit I think, and making me feel sort of disorientated and dizzy" (86 years, female) I didn't like so much the one with the glasses on. I preferred the screen because you could orientate yourself with your surroundings, whereas with that you couldn't. Or at least I couldn't" (Pt7, 81 years, male) "I found the system, once it was explained to me, it was quite simple to use. It was quite easy" (79 years, male)
Motivation	"I tend to think it would make it more enjoyable, because if you are on your own and doing ordinary exercises it becomes very mundane and you get disinterested quickly. But if you have the animation and that it makes it much more enjoyable (77 years, male)
Ability to participate	"It proves to me I can do it, it's been a long while since I did anything like that" (Pt7, 81 years, male) "you just had to be really alert to get your foot out and your foot in" (79 years, female) "I would prefer to have somebody... Well for instance you saying to me "Sit down, the chair is right behind you". You know it is going to be there, but still, it gives you the confidence to know that somebody is actually telling you that" (Pt7, 81 years, male)

3. DISCUSSION AND CONCLUSIONS

In line with available guidelines recommending user involvement early in the design process (Fisk et al. 2009; McLaughlin et al. 2012; Uzor et al. 2012; Proffitt and Lange 2013), this study involved older adults throughout the development process to improve users' perceptions of the usability and acceptability of the ACG system. Findings from this study suggested that ACG was safe way to deliver strength and balance exercise to older people. No adverse events were reported during use of the system. Participants unanimously preferred viewing the system displayed on flat screen rather than using a VR headset. While participants reported good levels of usability according to the SUS, they also required high levels of additional support to use the system.

One driver behind this project was to explore the possibility of developing a system that could be used safely and autonomously to meet the needs of more frail older adults who perhaps were unable to attend falls prevention therapy outside of their home. Older adults were involved throughout the development process in order to develop the system to meet their needs and preferences. Although not limited to older adults with high risk of falling, the user testing phase included participants with a history of falls. It documented the level of instruction and supervision needed to use the system to establish whether it could be used at home. Additionally, the use of both quantitative and qualitative measures to explore usability and acceptability of the system explained findings; for example, responses to semi-structured interviews explained the lower SUS score for the VR headset study condition.

Research to date reports limited information on the usability and acceptability of fully-immersive virtual experiences, such as VR headsets, system in this population. Participants who completed the VR headset study condition reported feeling disorientated, and there was a strong preference of the screen study condition. Ageing is associated with reduced sensitivity of sensory receptors (Goble et al. 2009); this is associated with an increased reliance on visual feedback for postural control (Simoneau et al. 1999; Woollacott and Shumway-Cook 2002). Older adults' experience of VR may be influenced by the disruption/ absence of visual feedback from the real environment when wearing the VR headset. Similar findings were also observed in balance-impaired adults aged 59-69 years who reported feeling insecure when playing a VR skiing game displayed using the Oculus Rift VR headset compared with on screen (Epure et al. 2016). Augmented reality may be a way to address this, by enabling older adults to interact with a virtual environment without losing visual feedback of their surroundings.

There were a number of limitations related to the study population and study design. The sample size of this study was small, potentially limiting the ability to draw conclusions based on its findings. However, research on the number of participants required for usability testing indicates the 5-10 participants are sufficient (Faulkner et al. 2003); with some suggestion that multiple small tests are more valuable in allowing iterative changes to be made based on findings with smaller numbers of users (Nielsen et al. 2000). As such, the current sample size is considered to have provided sufficient information to inform the development of the next stage of the study. The findings of this study suggested that older adults perceived ACG to be an acceptable way to deliver exercises for falls prevention; however, recruitment and conduct of the study was in day centres for older people. The specific population and setting may limit the generalisability of the findings to all older adults; however, the study population included those at high risk of falls, thus providing information about the perceptions of those most in need of an ACG intervention for strength and balance exercise.

Although higher for the flat screen version, SUS scores remained at the lower end of acceptable (Figure 3). Implementing user feedback may improve usability of the system. Findings from user testing were used to modify the system. This included choice of display to meet users' preferences; prototype 2 of the system was developed for display only on a flat screen. Findings from user testing of prototype 1, also suggested that a period of familiarisation was of benefit during the introduction of novel technology to older adults. Additionally, it was observed that with single use of the ACG system, high levels of additional instruction were required for use of the system. Therefore, it could be considered that future user testing should evaluate the safety, usability and acceptability of the ACG system with repeated use in older adults.

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Providing a means of pre-planning for real spaces for the visually impaired using updated navigation techniques in virtual reality: A system and experiment proposal

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ABSTRACT

This paper proposes a new Virtual Environment (VE) navigation system for the visually impaired; the goal of which is to explore the suitability of such technology in providing pre-planning aids for Real Spaces (RS). Past studies have utilised a variety of message framing techniques to convey spatial and object awareness within VEs; utilising both audio and haptic feedback mechanisms to illustrate directional information and/or object proximity and collision. However, few studies have examined the relationship between message framing techniques as appropriate metaphors for RS representation. Furthermore, methods of navigation within VEs are currently limited with past studies implementing a range of approaches from standard joysticks to virtual cane representation using off-the-shelf technology. There remains a need, therefore, to provide an intuitive means of navigation in conjunction with appropriate message framing for pre-planning aids such that the transition to the RS is as seamless as possible. This paper outlines a new system which utilises a Walking in Place (WIP) technique derived from Orientation Mobility Cane Technique to navigate VEs; this approach closely mirrors real world navigation. An experiment is proposed to evaluate the effectiveness of such an approach and to examine potential message framing techniques to appropriately represent real world spaces.

1. INTRODUCTION

The sophistication of modern Virtual Environments (VEs) provides new opportunities for accurate representations of Real Spaces (RSs) for the purposes of entertainment, exploration and training. However, interaction with VEs for people who are blind is difficult due to the obvious reliance on audio and haptic feedback rather than visual. Furthermore, research suggests that the blind utilise an egocentric spatial coding strategy that leads to a lack of wider reaching spatial awareness (Dodd et al. 1982); of objects in an environment for example. Exploring the use of VEs is therefore an important area of research in order to not only solve accessibility issues but also examine their use in providing pre-planning and training aids to RS navigation. Indeed, past work suggests that utilisation of video games and therefore virtual environments could promote more varied navigation strategies including more allocentric overview of understanding environments (Merabet et al., 2012) thereby providing a richer knowledge base of spatial understanding.

Similarly, the utilisation of off-the-shelf (OTS) technology has been explored as a means of providing blind people with methods of navigating VEs using the Wii Motion Controller (Evett et al. 2008). In such examples, VEs could represent RSs with the aim of providing a means pre-planning navigation for purposes of orientation and mobility training (O&M). Such technology could therefore provide methods of building effective cognitive maps that contain not just route information but also object and point of interest awareness within RSs. However, limitations in the technology affected the amount of training required to develop sufficient navigation skills within the VEs (Lahav et al. 2014). We therefore propose a new system of VE navigation for blind people that utilises Virtual Reality technology, mobile phones and an augmented cane with an increased array of sensors for mimicking RSs and the varied range of contextual stimuli found within them.

The purpose of this new system is therefore threefold:

1. To provide a new means of exploring Virtual Environments for the blind.
2. To provide a means of pre-planning navigation in RSs
3. To provide new methods of effective orientation and mobility training for real spaces.

This paper provides an overview of past systems and their navigation implementations, a proposal for our system utilising updated technology and an overview of future work including an outline of intended experiments exploring the effectiveness of the system.

2. RELATED WORK

Relevant research includes those that have examined methods of navigating virtual environments for the blind and the ways in which these have been utilised as pre-planning aids. Of particular interest are the ways in which objects, directions and other related navigational information is conveyed to user by the system.

Lahav et al. (2005) examined the effectiveness of VE's in assisting in the acquisition of mental maps through their navigation. Here a simple 2D representation of a real space provides the basis for interaction with haptic feedback simulating object texture and friction provided through a force feedback joystick and three types audio feedback: tapping sound when objects are "bumped", an audible alert when approaching object corners and footstep sounds throughout navigation. Findings suggest participants approached RS's with more confidence and with greater use of successful navigation strategies with prior exposure to the VE intervention.

Evett et al. (2008) expanded on this study by examining the use of the Nintendo Wii controlled to create an intelligent "virtual cane". A 3D VE representation of a RS provided the means of testing through comparison and an adapted WiiMote provided methods of navigation via multiple methods depending on the configuration. The rumble feature of the controller provided haptic feedback of object proximity through the strength of vibration; while, audio feedback also offered other distance information and object names. Findings suggest that the system supported the development of mental maps as participants could accurately describe the spaces explored. However, the sample size was small (N=3) and issues with the systems ease of use in navigation was a drawback. This study was later expanded on (Lahav et al. 2014) with an increased sample size drawing similar conclusions suggesting that VE's have a significant role to play in the creation of spatial mental maps of RS's. Similarly, Seki & Sato (2011) propose an acoustic Virtual Reality (VR) system that enables orientation and mobility training by accurately representing sounds and direction during navigation. Head tilting and a walking in place technique provided control within the environment unlike studies mentioned previously. Findings suggest that participants within the VR environment experienced less "veering" when compared to a real training group and that the intervention can reduce levels of stress.

Employing a VE in orientation and mobility training allows for additional features from that domain to be taken advantage of. For example, Connors et al. (2014) utilised similar approaches to those discussed here but with the addition of game-based learning features to aid in the O&M training; the route-learning system here took the form a goal-directed videogame. A keyboard and mouse formed the basis for interaction while iconic and spatialized sound cues offered contextual information about the environment. Again, results suggest that pre-planning through such system creates a stronger mental map of the associated RS and, interestingly, learning through game-based approaches can lead to the production of more flexible mental maps.

Studies examined thus far have looked at the ways in which VE's can be utilised as a pre-planning aid to learning about equivalent real spaces prior to physically visiting. However, the methods applied can also be utilised to aid in the navigation of RS's; for example, existing mobility aids could be adapted to expand the contextual information they convey. A study by Maidenbaum et al. (2014) proposes the "Eyecane" to increase the amount contextual information provided by a traditional white cane. Active sensors utilising narrow beams gauge the distance to objects in an environment providing audio and haptic feedback to the user.

It is notable that few studies appear to have explored both the mode of navigation within the virtual environment and effectiveness with which mental maps are transferred to real spaces. The purpose of this paper is to propose a new system that utilises modern sensors and techniques to utilise appropriate cane technique to explore virtual environments. This more intuitive mode of exploration could allow for both training and practice of that technique and the possibility for easier transfer from VE's to RS's.

2.1 Summary of Message Framing Techniques

The studies discussed previously employed a diverse range of techniques to convey spatial information through means other than visual. Given that the goal is to enable intuitive navigation of spaces (both virtual and real), the ease with which information is provided is key to ensuring the success of an intervention, the accuracy of behaviour in response to cues and the effectiveness of mental maps created for RS's.

Table 1 provides an overview of common message-framing techniques deployed in past research and projects.

Table 1. *Message Framing in Navigation Aids*

Name	Type	Description	Citation
Iconic	Audio	Audio representation of real objects; for example, door knocking sound to represent a door object.	Connors et al., 2014
Spatialized 3D Acoustic Display	Audio	Audio feedback with directional information; i.e. left audio channel utilised if the object is located on the left.	Connors et al., 2014 Seki & Sato, 2011 Loomis et al., 1998
Sonar	Audio	A series of beeps to indicate object proximity.	Evett et al., 2008
Text-to-speech (TTS)	Audio	Audio descriptions of objects within environments provided upon some form of selection.	Lahav et al., 2014 Connors et al., 2014
Sensory Substitution	Audio	Conversion of images to audio representation of different tonal notes and types.	Maidenbaum et al., 2016
Precise Force Feedback	Haptic	Complex representation of objects using precise force feedback devices; for example, multi-point gloves that give an indication of small object shape in a VE.	Magnusson et al., 2002 Clarkson et al., 2002
Broad Force Feedback	Haptic	Use of device rumble to indicate object collision or variation in vibration to indicate object proximity	Lahav et al., 2014

It is notable from table 1, that the feedback method is dependent on the means of environment interaction. For example, the use of precise force feedback is dependent on the utilisation of a specialist glove and is only applicable within VE's. Given that our aim is examine intuitive methods of VE navigation that is transferable to RS's, it is apparent that the interaction methods, in particular input methods for navigation, must be transferable between the two. Hence, we propose exploring the use of expanding traditional navigation methods in RS's (e.g. white cane) with an increased range of contextual feedback mechanisms to improve spatial awareness and the production of effective mental maps. This updated system builds on past work dealing with a "virtual cane" to navigate environments; in this work a physical cane is augmented to allow it to be used within VEs.

3. PROPOSED SYSTEM

Virtual representations of unknown RSs have been demonstrated to allow those with a visual impairment the opportunity to develop both mental-models and navigational strategies. Formulated in advance; these strategies can then can then be employed in the RS. Typically, such systems act to disrupt the match between both the mental body-model formed from proprioceptive data and the sensory data supplied by the VE. This is because the methods applied for navigation often require a mental association between peripheral input and the act of virtual translation. To evaluate the impact and ultimately combat this effect; this research employs alternative methods for navigation; based upon an amalgamation of Orientation Mobility Cane Technique (OMCT) and the
Walking in Place (WIP) technique. WIP is an established effective method to navigate VE. It enables an individual to traverse a VE without the physical limitations imposed by tracking devices; it has been shown to improve both an individual's level of immersion and their spatial orientation (Slater et al, 1995).

The application of WIP in this context allows a Visual Impairment (VI) user to traverse the environment with a technology-augmented cane in a similar manner to that of a real-world PE. Both a MARG (Magnetic, Angular Rate, and Gravity) sensor array and a rotary encoder are fitted to the cane allow for its orientation and usage to be tracked within the VE. Navigation is achieved via use of a custom walking distance estimation algorithm derived from the design and analysis of a custom cane-use walking classification. The classification itself has been derived via applied Orientation Mobility Cane Technique (OMCT). Through combining WIP with OMCT, the proposed system will allow for traditional navigation through a VE that mirrors that found in the real world providing a smoother transition between the two; furthermore, methods of evaluating cane technique through navigation will become available to future research.

The algorithm can track position of a through dead reckoning, with integral drift corrected for each time the operator completes a specific phase of the walk cycle. Not only does this allow for correctly performed OMCT to be applied as means for navigation within Virtual Environments; but also, potentially provides basis for a self-contained indoor positioning system.

A Virtual Reality capable mobile phone is utilised to run the Virtual Environment and further aid navigation; for example, through the use of audio cues. Indeed, past work has pointed out the need to utilise a variety of input channels when aiding navigation (Magnusson et al., 2002). This allows for a portable testing environment and access to extra sensors and processing capability on the device if required. For example, directional movement can be achieved via full body or head turning while locomotion achieved through the aforementioned WIP technique, mirroring navigation in RSs as closely as possible.

3.1 Force Haptic Feedback

In addition to the audible feedback provided by the virtual environment itself, the system employs two forms of motor driven force feedback to inform the user of the construct of the environment. The primary form of feedback is supplied via use of a brushless motor situated in the head of the cane. In this context, the motor acts to replace the standard assistive cane ball tip and its rotation effected to give indication of both environment terrain and obstacles. An additional motor within the handle can also be pulsed too further enhance the signal. Example applications of feedback include the breaking of the motor during an arc to indicate a collision within the environment; and pulsing of handle and tip to indicate rough terrain.

A summary of the proposed system is presented in figure 1.

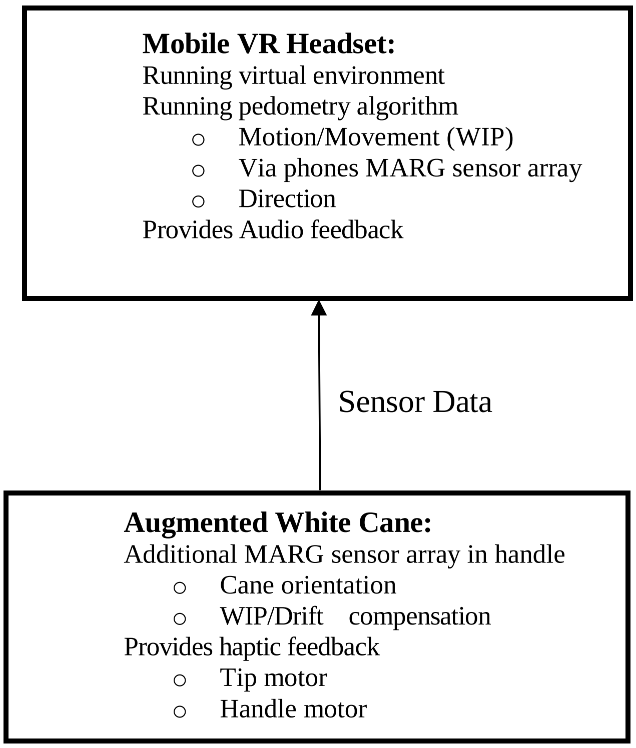

Figure 1. *Overview of the Virtual Cane System*

4. PROPOSED EXPERIMENTS

The previous section outlined a new system for pre-planning navigation and developing spatial mental models of real spaces using virtual environments. Through an augmented white cane, a variation of the WIP technique is utilised to navigate virtual environments using methods that intuitively mirror the real world.

From this new Virtual Cane system, and based on past research, the following research questions are derived:

1. What are the effects of the VE based navigation methods in the system in pre-planning for real spaces?
2. What are the effect of the VE based navigation methods in the system in the development of accurate spatial mental models of RS?
3. What are effective methods of message framing when utilising the VE based navigation methods in the new system?

To explore these research questions an initial controlled experiment is proposed derived from past studies of a similar nature. A series of simple maze designs will be constructed as virtual environments. These maze shapes will mirror those commonly found in research dealing with controlled experiments in spatial navigation; for example, the t-shaped maze and radial maze designs (Levy et al., 2005). The simple maze designs allow for full control over the experimental conditions and are relatively easy to reconstruct as real spaces. Past studies have sought to re-recreate existing real spaces; however, this prevents results from being reproduced by external parties and risks bias if prior exposure to that environment has occurred.

In order to explore research question one, participant will be provided with a variety of tasks (e.g. move from point A to point B) and asked to reproduce such navigation in an equivalent real space. Performance will be compared to a control who do not have any prior exposure to the RS through the VE. Performance will be determined as a measure of time taken to achieve the desired goal; i.e. length of time to traverse from point A to B. Furthermore, the traversal strategies implemented will be compared between the two groups of participants;
e.g. will users who have been exposed to the VE equivalent implement a different strategy of navigation to those who have not.

Research question two intends to examine the totality of the mental maps produced as a result of exposure to and navigation around an equivalent VE; there may be some overlap with RQ1, but this phase is primarily concerned with environmental awareness rather than navigation. Participants will be asked to explore the VEs within which will be placed a variety of objects throughout. Following participants will be asked to describe the environments they have navigated, and accuracy of the mental map assessed and asked to locate objects placed in the same location within the equivalent RSs. This version of the experiment will also allow navigational strategies to be assessed and to examine methods of encouraging allocentric views of spaces as suggested by past work (Merabet et al., 2012).

The final research question deals with evaluating effective message framing for navigation and object identification. With the addition of the haptic feedback mechanisms to the augmented cane and the use of the phone-based VR kit the range of options for message framing widens. Taking a user-centred design approach, we intend to develop suitable metaphors for object and environment recognition within VEs based on the real-world interaction techniques proposed here.

5. CONCLUSIONS & FURTHER WORK

This paper has sought to examine past work in VE navigation for users with visual impairments and identify the requirements for further work. Therefore, a new system is proposed that utilises a walking in place technique derived from orientation mobility cane technique to navigate virtual environments. This interaction method provides a clear parallel to real world methods of mobility for VI users and has the potential to provide more effective pre-planning tools through more accurate and holistic simulations of navigation.

Future work shall seek to carry out the described experiments to determine the effectiveness of the proposed system as a pre-planning aid to learning about real spaces. Work shall also seek to implement a user-centred study determining effective means of conveying spatial and navigational information. From this a set of VE metaphors for navigation and object identification will be developed for use in future implementations of virtual environments that cater to users with visual impairments. Future work may also explore the use of these environments and metaphors in the implementation of games targeted at users with VIs and could perhaps explore the effects of gamification on navigation and environmental pre-planning.

Finally, the use of an OMCT derived method of interaction provides the possibility of expanding the systems functionality in the future to include a method of evaluation and training in effective cane technique. This would therefore provide a safe VR environment for training and practice with a view to developing skill for eventual implementation within real environments. This could be of particular use for users who are newly blind and are required to learn cane-based navigation or for users who have perhaps learnt incorrect technique or developed bad habits. User tracking and data analytics embedded within the system could therefore provide a powerful tool in aiding those with VIs to eventually improve their confidence and real-world mobility.

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High-functioning autistic children programming robotic behaviour

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ABSTRACT

This study focused on examining the ability of high-functioning autistic children to program robotic behaviour and to understand how they describe and construct the robots' behaviour using iconic programming software. The robotic learning environment was based on iPad, an iconic programming software (Robogan), and EV3. The results of this study show how the participants succeeded in programming the behaviour of an "other" at different programming complexity levels (from simple action to combinations of states of two binary sensors and rule with subroutine). A transformation from procedural to declarative description was also found.

1. INTRODUCTION

This study focuses on how high-functioning autistic (HFA) children can design the behaviour of others, in this case their ability to program robotic behaviour in a robotic setup.

Autism spectrum disorder (ASD) is a complex developmental disorder that affects behaviour, social interaction, communication, and academic skills. Its exact causes are unknown, although it is thought to involve genetic, psychological, neurological, fragile health, and environmental factors. Baird et al. (2006) and Brugha et al. (2011) have described deficits in social communication and interaction across multiple contexts. Children with ASD have repetitive patterns of behaviour, interests, and/or activities and can have a wide range of symptoms, skills, and levels of impairment. Some are mildly impaired by their symptoms, while others are severely disabled. The *Diagnostic and Statistical Manual of Mental Disorders* (DSM-5) defines three severity levels for ASD: Level 1—requiring support; Level 2—requiring substantial support; Level 3—requiring very substantial support. These three levels differ in social communication and restricted, repetitive behaviours. HFA children usually have good communication skills and are inflexible in behaviour, causing interference with functions such as accepting change and switching between activities. In this study, focusing on HFA children, we suggest an innovative approach that for the first time enables HFA children to "design" the behaviour of smart artefacts by using their sensors to adapt in accordance with the environment. For most HFA children this would be the first opportunity to "design and control the behaviour of the other" not the "me", since usually they are the ones who are controlled by another.

In the past 14 years, there has been an increase in research and development of assistive technology for use by ASD children. The technologies enable them to communicate and to learn social and daily life skills. Dautenhahn, Werry, Salter, and Boekhorst (2003) discuss four potential benefits robots could provide as a device in autism therapy: robots allow simplified but embodied interaction, involving touch and physical manipulation; in terms of abstraction, robots are between the software and real world; interaction dynamics; and robots' naturally supporting multimodal interaction, including touch.

The responses to robot or robotlike characteristics in Aurora (Autonomous robotic platform as a remedial tool for children with autism) showed that ASD children preferred robots to passive toys (Dautenhahn & Werry, 2004), preferred robotlike characteristics over humanlike characteristics in social interactions (Robins, Dautenhahn, & Dubowski, 2006), and responded faster when cued by robotic rather than human movement (Bird, Leighton, Press, & Heyes, 2007; Pierno, Mari, Lusher, & Castiello, 2008). Tapus et al. (2012) and others (Greczek, Kaszubski, Atrash, & Mataric, 2014) have explored the Nao robot. Tapus et al. (2012) imitated gross arm movements of the child in real time. Different behavioural criteria (i.e., eye gaze, gaze shifting, free and prompted initiations of arm movements, and smile/laughter) were analysed based on the video data of the interaction. The results are mixed and suggest a high variability in reactions to the Nao robot. Standen et al. (2014) investigated the role of a humanoid robot in engaging the attention of young children with autism. Teachers of students with profound and multiple disabilities described actions they wished the robot to make in order to help nominated students achieve learning objectives. They identified a wide array of learning objectives, ranging from an appreciation of cause and effect to improving the pupil's sense of direction. The robot's role could be to reward behaviour, provide cues, or provide an active element in learning. Rated engagement was significantly higher with the robot than in the classroom. Bekele, Crittendon, Swanson, Sarkar, and Warren (2014) confirmed the hypotheses that children with ASD would pay more attention to a humanoid robot than a human being and that children would be more accurate in working with the robot than with a human. Similarly, in mobile robot research Duquette, Michaud, and Mercier (2007) found that two children paired with a robot mediator demonstrated increased shared attention and imitated more facial expressions compared to the children paired with a human mediator.

Turkle (1984) and Ackermann (1991) researched what conceptual perspectives guided children's thinking about the behaviour of robots. Both found two different frameworks: the psychological (such as animate intentions, emotions, personality, and volition), and the physical or technological (such as gears, motors, sensors, and control program). Levy and Mioduser (2008) examined these two conceptual perspectives among kindergarten children. They found two distinct patterns: "engineering" a technological perspective, where the young children were focused on the technical workings and the behavioural building blocks of the robot; and "bridging", which combined two distinct perspectives: psychological and technological. They found a relation between the task's complexity and type of conceptual perspectives. Subsequent research by Mioduser, Levy, and Talis (2009) examined how kindergarten children explain a robot's behaviour; they found that kindergartners abstracted rules from observing a robot's behaviour, a process marked by increased generalization, a shift from temporal to atemporal constructs, and decentering from the robot to include its environment. Throughout this process, their representations shifted from episodes to scripts to rules, in other words from a procedural to a declarative description.

In this study, the robotic learning environment was based on the iPad and an iconic programming (Robogan), and EV3, a smart robot that allows the HFA child to design and program its behaviour independently. This iconic programming compensates for poor communication, writing, or reading skills and offers ease of use to HFA children without the need to read or write commands in letters. The Robogan uses rule-based programming, a declarative approach to programming, in addition to the standard procedural approach of script programming. Furthermore, feedback for the programming action is presented immediately by the robot action and not by a therapist.

The main focus of this study is to examine the ability of HFA children to program robotic behaviour, to understand how they describe and construct the robot's behaviour at different programming complexity levels via Robogan, and to examine if and how the narrative of task influences the participants' performance. At the theoretical level, we expect to contribute to the expansion and consolidation of knowledge about the learning and construction process of behaviour of smart artefacts through the observation of iconic programming by HFA children.

2. METHOD

2.1 Participants

Two participants participated in this study: A. and N. both are Level 1 HFA children of average age 10.5; neither takes medication regularly. Both participants are integrated in local public school. Both regularly use a computer independently. The University Ethics Committee and Ministry of Education Ethics Committee have approved this research.

2.2 Research Variables

The independent variable included two variables: (a) the complexity of robot programming, which included six levels of complexity from simple action, teach, programming with or without subroutine, half rule, one rule, and two sensors (see Figure 2) and (b) the narrative of task (using a narrative or symbolic approach).

Three groups of dependent variables were defined: description task, programming task, and learning task.

The participants' description task included four variables: (a) rules identification, (b) description features (technology terminology or anthropomorphic language), (c) description type (procedural or declarative approach), and (d) complexity of explanation (simple or complex).

The participants' programming task included six variables: (a) response time, (b) success, (c) debugging loop, (d) detection and repair debugging, (e) support tool, and (f) researcher intervention.
The participants' learning tasks included six variables, which were the same as the variables in the programming task.

2.3 Research Instruments

Three research instruments were developed for this study:

- *EV3 Robot.* The robot was built from Lego Mindstorms EV3 flexible kit (Figure 1). This kit combines sensors, motors, and an electronic brain. This is the newest way to learn to build and program a robot.

Figure 1. EV3 robot**.**

- *Robogan.* This is a free visual programming language app, developed especially for young children for research purposes (Mioduser et al., 2009; Mioduser & Kuperman, 2012; Gilutz, Raveh, & Mioduser, 2015). The Robogan allows the user to program the robot's movements in open and closed loop (with and without sensors). The Robogan is a visual programming language that provides iconic elements, which can compensate for poor communication, writing, or reading skills, and offers ease of use to HFA children without the need to read or write commands in letters. It is based on a fixed-position key interface through all the levels of complexity. It applies rule-based programming—a declarative approach to programming—in addition to the standard procedural approach of script programming. Furthermore, feedback for the programming action is presented immediately by the robot action and not by the researcher. This application runs on an iPad, divided into six modes of varying degrees of complexity, and allows programming of the robot's behaviour in a simple and intuitive manner (Figure 2).

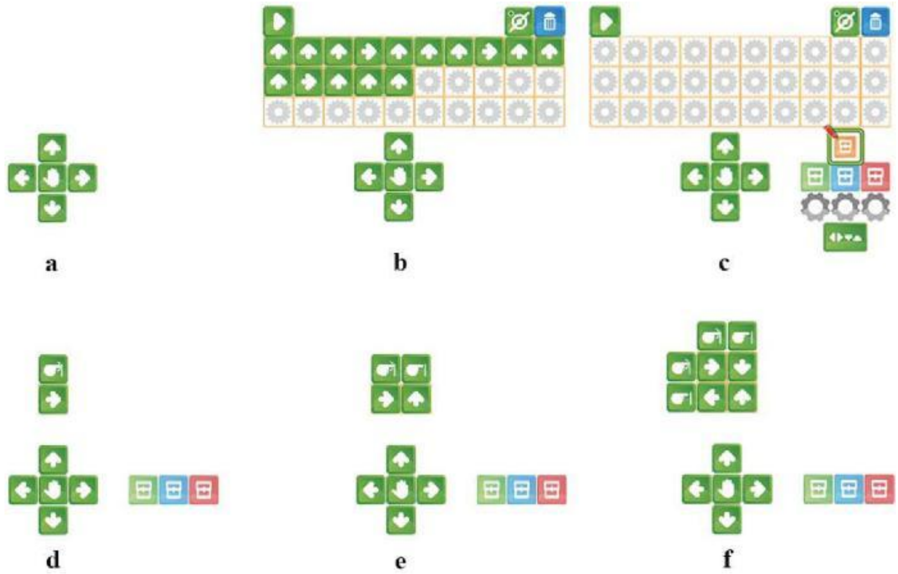

Figure 2. Robogan Modes: (a) Mode 1 simple action; (b) Mode 2 the action with a view of the entire sequence; (c) Mode 3 programming with or without subroutines; (d) Mode 4 half rule with one sensor; (e) Mode 5 one rule with one sensor; and (f) Mode 6 two sensors.

The Robogan's seven modes are:
Mode 1: Simple action. A click on the appropriate interface button will lead the robot to perform one simple action: a step forward, a step back, a turn right, or a turn left (Figure 2a).

Mode 2: Teach. Perform the action with a view of an entire sequence. Robot control is as in Mode 1, but here the entire step sequence is recorded on the screen and the entire sequence of recorded actions can run in automatic mode (Figure 2b).

Modes 3 and 4: Programming with or without subroutines. Unlike Mode 2, the robot performs the whole sequence of recorded actions in automatic mode at the end of the programming process. In this mode, it is possible to create and use subroutines (Figure 2c).

In the following steps, binary sensors (touch, light, etc.) are used to program the robot's behaviour.

Mode 5: Half rule with one sensor. By dragging the corresponding icon, the user selects the action that the robot will perform during the transition of a binary sensor in one of the states (Figure 2d).

Mode 6: One rule with one sensor. The user selects actions for the two states of the binary sensor (Figure 2e).

Mode 7: Two sensors. User selects actions for all combinations of states of the two binary sensors (Figure 2f).

- *Robotic Environment Setting.* This environment includes all the components that are used in the constructed tasks, such as a variety of layouts, obstacles, and robot outfits (Figure 3).

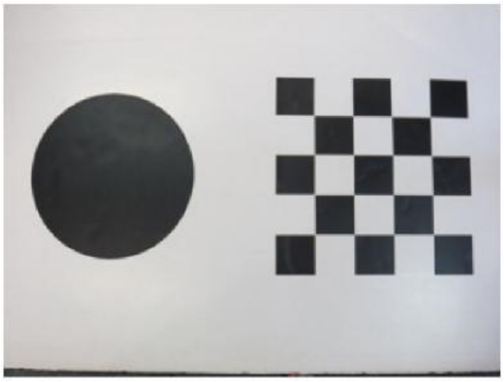

Figure 3. The robotic environmental setup.

2.4 Data Collection Instruments

Seven data collection tools were developed for this study:

- *Background Questionnaire.* Participant's parent questionnaire including personal information and participant's computer technology knowledge (12 questions).
- *Technology Knowledge Questionnaire.* A two-part participant questionnaire. The first part had seven open questions about participant's use of information technology devices. The second part included 12 multiple-choice questions on mechanics based on the Bennett Mechanical Comprehension Test (Bennett, 2008).
- *Understanding of Robot Behaviour Pre- and Posttest.* Identical assessment was given before and after learning about the robot. We placed obstacles in the robotic environment; the robot was programmed in advance using the rule: if the touch sensor was touched, then step backward and turn right 90 degrees, otherwise drive straight. The participant observed a robot's behaviour several times and was asked: "What is the robot doing?"
- *Description Tasks.* Three description tasks were designed based on the Robogan application.
- *Programming Tasks.* These tasks aimed to teach the participant how to program through the Robogan application. They were designed in increasing difficulty according to the configurations of rules required to perform tasks. They were followed by one or more new programming tasks.
- *Observations.* Participant's construction and verbal description were videorecorded during all sessions.
- *Screen Recorder.* The user's programming activities using the Robogan were recorded, with a screen recorder app.

2.5 Data Analysis

Data analysis involved qualitative and quantitative analyses; these data focused on questionnaires, pre- and posttest questionnaires, participant's performance, interactions, and learning process.

2.6 Procedure

This research took place at the participants' public school. During the study, both participants worked and were observed individually. At the first stage the parents were fully informed of the research framework and signed the consent form, followed by their answering the background questionnaire. At the first meeting the participants received a short verbal explanation about the experimental process. Next, they answered the technology knowledge questionnaire and the pretest on their understanding of robotic behaviour. Following these stages, they were trained on the Robot EV3's and Robogan app, learning the six modes from simple action (Mode 1) through two sensors (Mode 6). A posttest was conducted after the programming stage on the participant's understanding of robotic behaviour.

The length of each session was adapted to the participant's needs and spanned from 12 to 31 minutes (a total of 14 sessions, overall length 04:19 hr).

3. RESULTS

How did the HFA participants describe the robot's behaviour at different programming complexity levels?

Using the pre- and posttest, we examined the participants' ability to understand and to verbally describe the robotic behaviour before and after they learned how to program the robot. In the pretest, both participants used anthropomorphic description features, such as, A.: *"His mission is to pass? .. His mission is to pass them [the obstacles]? He went crazy ... The robot became crazy ... He just walked... He just drove... he wanted to get out of it ... from this thing..."* N.: *"He drives forward and then blocks him and he goes backward and he turns and ...he's going forward again..."*. Both provided simple and procedural types of description. At the posttest, both participants' verbal description displayed technology description features and used declarative description type. Comparison of both verbal descriptions in the pretest and the posttest results revealed a transition in the description features from anthropomorphic to technology features and from procedural to declarative description. In complexity both descriptions remained simple with no rules identification of the robot's behaviour.

Table 1. *Pre- and posttest verbal descriptions about the robots' behaviour.*

	Pretest		Posttest	
	A	N	A	A
Rules identification	No	Yes	No	No
Description features	Anthropomorphic	Anthropomorphic	Technology	Technology
Description type	Procedural	Procedural	Procedural and declarative	Declarative
Description complexity	Simple	Simple	Simple and complex	Simple

While learning to program the participants were asked three times to verbally describe the robot's behaviour, at the fifth, sixth, and seventh modes—half rule with one sensor, one rule with one sensor, and two sensors. In early description tasks both participants were able to identify robotic behaviour rules. For example, A.: *"He goes when it's been touched."* In these early description tasks the participants included in their descriptions anthropomorphic features and later progressed to using technology features. For example, A.: *"But we still have not found a name for the robot... he likes black..."* became: *"The touch sensor and the light sensor activate and it moves forward."* N.: *"he* [the robot] *wants to..."* became: *"When he sees white he turns around; when he sees black he continues..."*. All verbal descriptions included declarative descriptions, such as, A.: *"driving... and on white turning."*

Table 2. *Verbal descriptions tasks.*

	Half rule with one sensor		One rule with one sensor		Two sensors	
	A.	**N.**	**A.**	**N.**	**A.**	**N.**
Rules identification	Yes	Yes	Yes	No	No	N/A
Description features	Anthropo-morphic	Anthropomorphic	Anthropomorphic and Technology	Technology	Technology and Anthropomorphic	
Description type	Declarative	Declarative	Declarative	Declarative		
Description complexity		Simple		Simple just action		

How did the HFA participants perform the programming tasks at different programming complexity levels via Robogan?

In most of the programming tasks (P) the participants succeeded in programming the robot behaviour in accordance with the robotic scenario (92%). They had difficulties in performing programming tasks mainly in one mode—programming mode with subroutines (Mode 4). The number of debugging loops decreased each time they performed a new programming task in each mode. A high number of debugging loops were found in two modes: programming mode with subroutines (Mode 4) and programming tasks that involved two binary sensors (Mode 7). In programming tasks that involved robot movement in open loop the participants tended to use hand and eye estimation to estimate distances and movement. The participants did not experience spatial difficulties in determining the robot's orientation in most of the tasks (97%), although in most they were seated in a position different from the robot's. Only once did N. need to enter the robot scenario to orient himself to the robot orientation before programming.

Table 3. *Performance of programming tasks.*

Mode	Tas	n	Success	Debugging loops	Support
1	P1	A	Yes	0	Eye estimation; question to researcher
		N	Yes	1	Question to researcher
2	P1	A	Yes	0	Eye estimation
		N	Yes	0	
	P2	A	Yes	3	Eye estimation
		N	Yes	0	
	P3	A	Yes	0	Eye estimation
		N	Yes	0	Eye estimation
3	P1	A	Yes	1	Eye estimation
		N	Yes	1	Eye estimation
4	P1	A	Partially	4	Eye and hand estimation; question to researcher
		N	Partially	4	Eye estimation; question to researcher
	P2	A	Yes	3	Eye estimation
		N	No	2	
	P3	A	Yes	0	
		N	Yes	0	Hand estimation; entering robot scenario
5—touch sensor	P1	A	Yes	0	
		N	Yes	2	
	P2	A	Yes	1	
		N	Yes	1	
5—light sensor	P1	A	Yes	0	
		N	Yes	2	
	P2	A	Yes	1	
		N	Yes	1	
6 —touch sensor	P1	A	Yes	0	
		N	Yes	2	
	P2	A.	Yes	1	
		N.	Yes	1	
6—light sensor	P1	A.	Yes	1	
		N.	Yes	1	
	P2	A.	Yes	0	
		N.	Yes	0	
7	P1	A.	Yes	0	Question to researcher
		N.	Yes	2	
	P2	A.	Yes	4	
		N.			
	P3	A.	yes	2	Question to researcher
		N.			

How did the narrative of the task influence the participants' performance?

In this study, we examined two types of task description: narrative and symbolic. For example, the robot was presented to the user as a boy needing to cross the street and who must look left and right each time he arrives at an intersection; or as an orange circle that must turn left and right each time it arrives at a black line. The study results show similarities between the participants' programming achievement without influence of the type of narrative applied to the task. With both types of cover stories, after the researcher presented the task, the participants chose the narrative (*"robot wants to..."*) instead of the symbolic role.

4. DISCUSSION

The study reported here is part of a research effort aimed at understanding if and how HFA children are able to program the behaviour of others, in this case examining their ability to program robotic behaviour in a robotic setup. The results of this study helped us to elucidate several issues concerning the contribution of the programming tasks by HFA children.

"Design" the behaviour of smart artefacts. The participants were able to design the behaviour of smart artefacts by adapting use of their sensors in accordance with the environment. As in the research by Mioduser et al. (2009), the HFA participants in this study succeeded in programming the robot's behaviour in accordance with the robotic scenario.

Narrative or symbolic stories to match programming tasks. HFA children do not need symbolic features to be able to program a robot's behaviour. The study results show identical results in the participants' programming achievement regardless of the type of the narrative that was applied to the task. In neither narrative, nor symbolic type did the participants refer to the symbolic robot character or robotic scenario.

Robot's Behaviour Description. The participants explained the robot's behaviours at first by shifting from anthropomorphic to technology description features. In complex tasks, such as programming actions for all combinations of states of the two binary sensors, they tended to choose anthropomorphic or a mixture of features (anthropomorphic and technology) as found in past research by Levy and Mioduser (2008). At the posttest, both participants' verbal description had transitioned from procedural to declarative descriptions. It demonstrated that the Robogan application allows the user to move from a procedural approach to a declarative approach (rule based) at the programming tasks of the robot's behaviour. Resembling the findings of Mioduser et al. (2009), as the participants practised more programming tasks, their descriptions changed from procedural to declarative description.

5. CONCLUSIONS

These research results have important implications for the continuation of the research and for its implementation. Further studies might focus on programming approaches and skills or knowledge transfer: (a) exploring HFA students' programming skills using programming software based on a declarative approach (e.g., Robogan) compared with other programming software based on procedure approach (e.g., Scratch) and (b) examining the ability of HFA children to transfer knowledge and strategies from the Robogan scenarios to real life scenarios.

For implementation, this research study's results on HFA children's ability to program robot behaviour can be implemented in K–12 education. HFA children are integrated in public schools, and this research demonstrates that they can be integrated with their peers in computer and robotic disciplines. Also, they can learn about the technology that surround them, learning how it works and how to control it. The declarative approach discussed in this study, is an abstractive approach that helps participants cope with programming tasks. We can extend this problem-solving method based on the declarative approach to aid HFA children in solving other types of problems.

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A low-cost Kinect for Windows v2-based spatiotemporal gait analysis system. Efficacy study with healthy subjects and individuals with stroke

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ABSTRACT

Gait disorders are common in a variety of musculoskeletal and neurological conditions and can have a strong impact on independence and quality of life. In the clinical setting, gait assessment is commonly performed with standardized clinical scales. Although fast and easy to administer, conventional tools usually have poor accuracy and sensitivity, and could be biased. Although different instrumented gait analysis systems have been proposed, their price and spatial and technological requirements have prevented their use in the clinical daily practice. We have developed a free web-based tool that enables gait analysis using the low-cost and portable Kinect for Windows v2. A total of 355 healthy and 50 individuals post-stroke were recruited to obtain a healthy pattern and to determine the concurrent validity of the system with conventional scales. All the participants were evaluated with the Kinect v2-based gait analysis system and, in addition, functional gait of post-stroke participants was assessed with traditional scales. Individuals with stroke showed reduced gait speed, slower and shorter strides, and wider steps compared to healthy age-matched controls. Significant correlations with variable strength emerged between the Kinect v2-based gait analysis measures and most of the standardized clinical tests. Healthy participants obtained better measures than individuals post-stroke did. The system showed high and moderate concurrent validity with clinical scales and it proved to be a reliable and feasible tool to assess the gait in individuals with stroke.

1. INTRODUCTION

Gait disorders are caused by a wide range of factors and are common in different pathologies of musculoskeletal origin, such as rheumatoid arthritis, and as well as neurological origin, such as stroke, Parkinson disease, or multiple sclerosis (Moon et al., 2016; Sánchez-Lacuesta et al., 2006), which can affect walking in the community and, consequently, independence and quality of life (Khanittanuphong & Tipchatyotin, 2017; Perez-Lloret et al., 2014; Price & Choy, 2018). Aging is also an important factor of gait. Healthy older adults show reduced speed (Almarwani et al., 2016) and exhibit greater gait variability in temporal and kinetic parameters when compared to young adults (Chester & Wrigley, 2008; Kobsar et al., 2014).

Gait analysis enables quantification of deficits and identification of fall risk (Simila et al., 2015). In addition, from a rehabilitation perspective, adequate assessment of gait-related deficits, as other impairments, is of great importance to establish customized interventions. In the clinical setting gait is commonly assessed through clinical scales. Conventional tools usually provide standardized measures of gait-related functions, and are rapid and easy to administrate. In contrast, they lack the accuracy and specificity necessary to detect abnormal gait events, which can otherwise remain unnoticed after clinical examination. Moreover, their results can be affected by possible bias of examiners' subjective evaluations.

Different instrumented solutions have been presented aiming to overcome the limitations of traditional clinical scales. Force plates (Hansen et al., 2002) and instrumented walkways have been used to detect spatiotemporal parameters of gait (Menz et al., 2004) from ground reaction forces and pressure applied to sensors fixed on the floor. Systems based on wearable inertial sensors allow for interpretation of human kinematics and spatiotemporal gait parameters from forces, angular rates, and sometimes the magnetic field surrounding the body (Sprager & Juric, 2015). Similarly, optical motion capture technology provides excellent accuracy and robustness at acquiring the position of reflective markers that are attached to specific body parts, from which kinematic and spatiotemporal measures can be computed (Kidder et al., 1996). Although these systems can provide quantitative, objective, and accurate evaluation of gait parameters, they usually have high costs, take up significant space in the clinic, are difficult to configure and manage, and are time-consuming. All these factors could have limited their widespread used in the clinical daily routine (Krebs et al., 1985).

The Microsoft Kinect (Microsoft, Redmond, WA) is a low-cost infrared camera that enables markerless human motion tracking by estimating the 3D position of the main human joints from depth information of the scene. This device showed comparable results to optical motion capture systems (Pfister et al., 2014) and it has been reported as a valid tool for assessing spatiotemporal gait parameters (R. A. Clark et al., 2013; Springer & Yogev Seligmann, 2016; Stone & Skubic, 2011). The second generation of the device, the Kinect for Windows v2 or Kinect v2, presents some upgrades in several features such as depth sensing accuracy, field of view, number of joints tracked, and simultaneous users. As its predecessor, the Kinect v2 has been compared with marker-based three dimensional motion analysis systems, evidencing similar and improved reliability (R. A. Clark et al., 2015). Preliminary studies have provided promising results when using the Kinect v2 to estimate spatiotemporal and kinematic gait parameters in healthy young adults (Dolatabadi et al., 2016; Mentiplay et al., 2015). The results on healthy population were confirmed on treadmills (Auvinet et al., 2015; Eltoukhy et al., 2017) and improved using a multi-Kinect v2 instrumented walkway (Geerse et al., 2015). Although there is an increasing body of evidence that supports the use of the Kinect and Kinect v2 for gait analysis with some reliability, the unavailability of the software, the limited testing on pathological subjects, and the absence of a healthy pattern to compare the results could compromise the clinical relevance of these results.

We have designed an open-access web-based tool that allows clinicians to perform spatiotemporal gait analysis using a low-cost Kinect v2 and generates clinical reports with absolute measures and in comparison to an age-matched sample of healthy individuals. The objective of this study was twofold: first, to compare the performance of healthy and individuals post-stroke in the Kinect v2-based gait analysis; and second, to determine the concurrent validity of the test with conventional clinical tests in individuals post-stroke.

2. METHODS

2.1 Participants

Healthy subjects were recruited to define the healthy pattern in the test. Subjects older than 10 years old, with no musculoskeletal disorders, and without arthritic or orthopedic conditions affecting the lower limbs were potential candidates to participate in the study.

Individuals post-stroke who satisfied the inclusion criteria described in Table 1 were recruited from the outpatient service of the long-term neurorehabilitation unit of Vithas-NISA Hospitals network.

Table 1. Inclusion and exclusion criteria of the post-stroke participants

Inclusion criteria	Exclusion criteria
• Age ≥18 and ≤80 • Ability to walk 10 meters indoors • Ability to understand instructions (Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975) >23)	• Individuals with severe aphasia (Mississippi Aphasia Screening Test (Romero et al., 2012) <45) • Individuals with permanent fixed contracture of joints in the legs • Individuals with arthritic or orthopedic conditions affecting the lower limbs • Individuals with severe hemispatial neglect.

Ethical approval for the study was granted by the Institutional Review Board of Vithas-NISA Valencia al Mar Hospital. All eligible candidates who agreed to take part in the study provided written informed consent.

2.2 Instrumentation.

The Kinect v2 was used to obtain the 3D pose and track the participants' movements during the testing. A Dell Inspiron 7520 (Dell Inc., Round Rock, TX) that included an 8-core Intel® CoreTM i7-3632QM @ 3.60 GHz, 8 GB of RAM, and AMD Radeon HD 7730M was used to run the software.

2.3 Software

The Kinect v2-based gait analysis system is controlled by an open-access webpage (Latorre et al., 2018b) that guides users throughout the process (Figure 1). It runs the test, compares the performance with a matched sample that is stored on a database, and finally, create a complete report of the results. An application that must be locally installed runs the test, retrieves data from the Kinect v2, and uploads the results to the webpage. The web platform was programmed in .NET using Visual Studio (Microsoft®, WA). SQL Server (Microsoft®, WA) was used to design the database. The application was implemented using Unity 3D (Unity Technologies, San Francisco, CA). Motion tracking data was registered using the Kinect for Windows Software Development Kit 2.0 (Microsoft®, WA), which provided the position of 25 joints in an area that ranged from 0.5 to 5 m to the device.

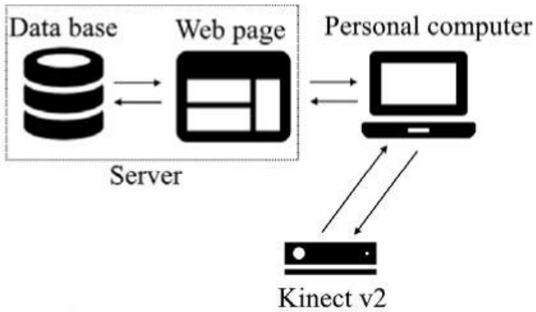


Figure 1. *Flow chart of the Kinect V2-based gait analysis system.*

During the test, the application provides examiners with visual feedback of the user's performance (Figure 2). A frontal and a sagittal view of a virtual skeleton composed from the data registered by the Kinect v2 are provided in the upper area of the application. A frontal RGB video stream of the users' performance with their virtual skeleton superimposed is provided in the lower left corner of the application. After each trial, a slider in the lower right corner of the application allows for visual inspection of the performance. The frontal and sagittal view of virtual skeleton is animated according to the position of the slider. After checking the performance of the user in each repetition, an examiner can validate the results or repeat the test (if any technical issue or abnormal performance occurred). If the repetition is validated, the application estimates and stores the mean value of the main spatiotemporal gait parameters that are detected: Speed (m/s), stride length (m), stride time (s), step length (m), step time (s), step width (m), cadence (steps/min), step asymmetry (m), swing left time (s), swing right time (s), first double support time (s), second double support time (s). It is important to highlight that information about ankle kinematics is not provided, as the tracking of this joint by the Kinect v2 has poor reliability (Eltoukhy et al., 2017; Llorens et al., 2015). Gait events are detected as described in (R. A. Clark et al., 2013; Latorre et al., 2018a; Mentiplay et al., 2015).

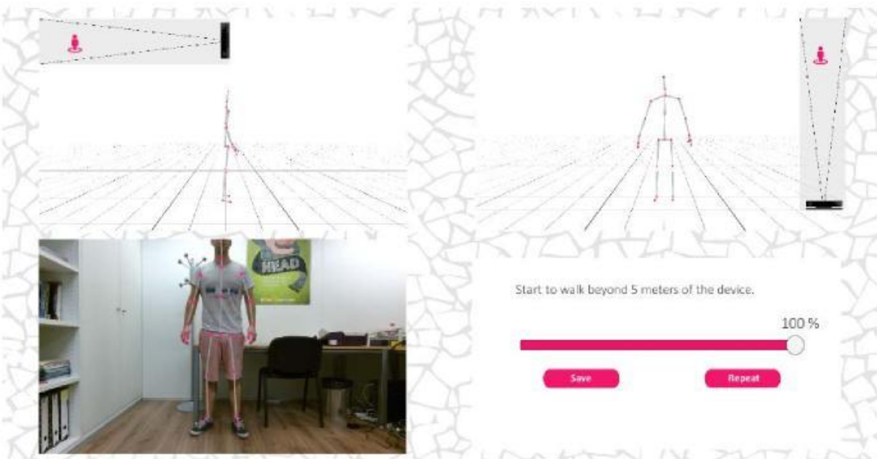


Figure 2. *Application user interface.*

2.4 Procedure.

Both healthy and post-stroke participants were assessed by an examiner with the Kinect v2-based gait analysis in dedicated areas free of objects and distractors. The assessment of post-stroke participants was done in the physical therapy area of four different hospitals.

Before experimentation, the examiner explained the objective of the test. Participants, who were initially located at 6 meters from the device in its longitudinal axis (z axis in coordinates of the Kinect v2) (Figure 3), were asked to walk towards the camera at a comfortable speed. A minimum of three repetitions was required. The examiner validated or repeated each repetition, as appropriate. A preliminary attempt, which was not included for analysis, was allowed to confirm that participants understood the test.

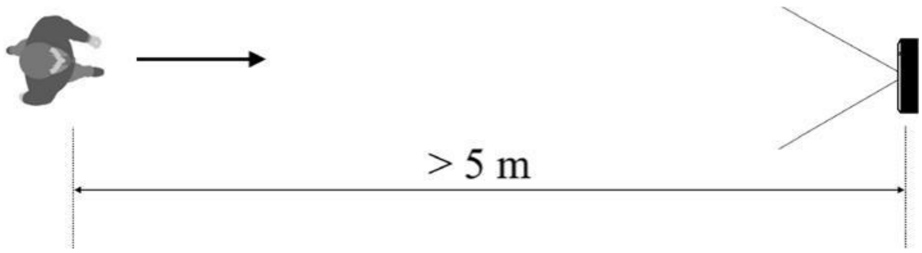


Figure 3. *Set up image.*

Post-stroke participants were also assessed with the Dynamic Gait Index (Jonsdottir & Cattaneo, 2007; Shumway-Cook & Woollacott, 1995), the 1-minute Walking Test (McDowellet al., 2005), the 10-meter Walking Test (Rossier & Wade, 2001) within the same day.

2.5 Data analysis

Healthy and post-stroke participants were grouped into seven age groups by decade. For each age group, the mean value of each spatiotemporal gait measure was estimated.

Pearson correlation coefficients were calculated to determine concurrent validity of the Kinect v2-based gait system with clinical tests. Values 0.8 or higher were accepted as indicating excellent reliability. Values in the range of 0.6–0.8 and 0.4–0.6 indicated high and moderate reliability, respectively (Llorens et al., 2015; Llorens et al., 2016). All statistical analyses were performed using IBM SPSS Statistics version 22 (IBM, New York, NY). Two-sided p-values of <0.05 were considered statistically significant.

3. RESULTS

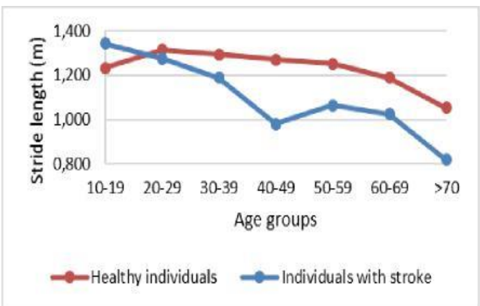
3.1 Participants

Fifty individuals with stroke (28 men and 22 women) participated in the study. Participants had a mean age of 51.06±15.99 years old and presented either ischemic (n=35) or hemorrhagic stroke (n=15), with a mean time since injury of 735.47±761.94 days.

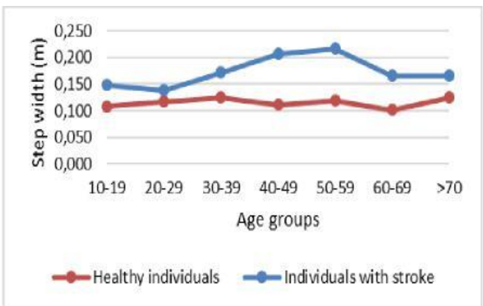
A total of 355 healthy individuals (169 men and 186 women) with a mean age of 44.7±21.2 years old were also enrolled for the healthy response pattern.

3.2 Comparison between healthy and individuals post-stroke

By and large, individuals with stroke presented reduced gait speed, showed slower and shorter strides, and wider steps (larger orthogonal distance between ankles in ground contact position), when compared to healthy age-matched controls. Results of both populations by each decade are depicted in Figure 4.



a)



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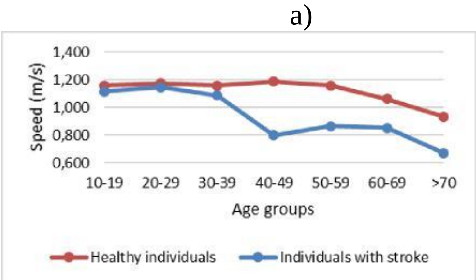
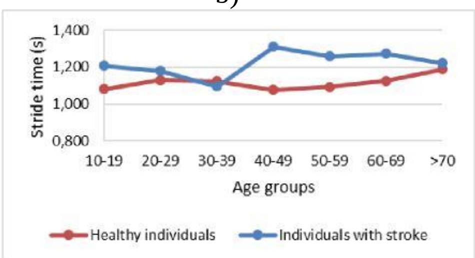


c)



d)

Figure 4. Mean results for post-stroke and healthy individuals divided by age in a) speed; b) stride time; c) stride length; and d) step width.

3.3 Concurrent validity

Significant correlations emerged between the measures provided by the Kinect v2-based gait analysis and the standardized clinical tests (Table 3). Strength of the correlation ranged from weak, which was obtained for asymmetry, swing left, and first double support time, to strong, which was obtained for the speed. Moderate correlations were found for the stride and step time and length, step width, cadence, swing right, and second double support time. According to the sign of the correlation, better performance in spatiotemporal measures of gait was consistent with better performance in the clinical scales. For instance, higher gait speed was associated to higher score in the Dynamic Gait Index, higher distance walked in the 1-minute Walking Test, shorter time during the 10-meter Walking Test.

Table 3. *Concurrent validity with clinical measures.*

Spatiotemporal parameter	Dynamic gait index	1-minute walking test	10-meter walking test
Speed (m/s)	r=0.762**	r=0.695**	r=-0.757**
Stride length (m)	r=0.758**	r=0.596**	r=-0.717**
Stride time (s)	r=-0.599**	r=-0.621**	r=0.720**
Step length (m)	r=0.710**	r=0.606**	r=-0.687**
Step time (s)	r=-0.619**	r=-0.636**	r=0.713**
Step width (m)	r=-0.271	r=-0.206	r=0.311*
Cadence (steps/min)	r=0.542**	r=0.624**	r=-0.646**
Step asymmetry (m)	r=0.033	r=0.186	r=-0.104
Swing left time (s)	r=0.295*	r=0.194	r=-0.343*
Swing right time (s)	r=0.478**	r=0.342*	r=-0.404**
First double support time (s)	r=-0.392**	r=-0.383**	r=0.250
Second double support time (s)	r=-0.559**	r=-0.517**	r=0.727**

* $p < 0.05$. ** $p < 0.01$.

4. DISCUSSION

The study presented in this paper compared the performance of healthy and individuals post-stroke in a portable low-cost Kinect v2-based gait analysis system and determined the concurrent validity of the test with conventional clinical tests in individuals post-stroke. Results evidenced that healthy participants had better performance than individuals post-stroke in almost all the measures of the test and showed high and moderate concurrent validity with clinical scales for gait speed, and stride and step time and length, step width, cadence, swing right, and second double support time, respectively. Gait speed and stride length decreased with age in both populations, which has been repeatedly reported in previous studies (Chen et al., 2005; Samson et al., 2001).

Although comparable, our results in healthy population present dissimilarities with those reported in previous studies, showing, for instance, lower gait speeds values (Murray et al., 1966; Oberg et al., 1993), which could be explained by differences in the methodology. In contrast to common procedures of gait analysis, where acceleration and deceleration phases are discarded to enable comparison (Wang et al., 2012), the limited depth range of the Kinect v2 forced to include these phases in the analysis. However, it is important to highlight that previous reports of normal responses also present discrepancies between studies (Obuchi et al., 2018). Several factors such as characteristics of the experimental setting (presence of distractors, indoor/outdoor condition, etc.) and participants (height, age, etc.) can affect gait. Despite of this limitation, the consistency of the methodology throughout all the study allows for comparison between populations. Differences between healthy and individuals post-stroke detected in our study are supported by a great body of evidence (Cao et al., 2017; R. a Clark et al., 2012; Vernon et al., 2015) and could be explained by sensory-motor impairments caused by the injury to the brain. However, acceleration and deceleration phases can affect individuals post-stroke and healthy individuals in a different matter, which could have also affect the results (Ng et al., 2016).

The moderate and high correlations found between clinical scales and the main spatiotemporal gait parameters (speed, stride, and step) are in line with previous reports (R. A. Clark et al., 2015; Dolatabadi et al., 2016), which supports the concurrent validity of the Kinect v2-based gait analysis. The absence of interactions between step asymmetry and clinical tools could evidence the lack of specificity of conventional tools to identify abnormal gait patterns. Although individuals with stroke presented gait asymmetries, a common gait behavior in case of hemiparesis (Olney & Richards, 1996; Patterson et al., 2008), it seemed not to affect their performance in functional gait tests. This could be explained by possible compensatory strategies, repeatedly reported in stroke patients (Choi & Kang, 2015), which can influence considerably the results in the clinical scales.

Although the Kinect v2 has limited accuracy (R. A. Clark et al., 2015; Dolatabadi et al., 2016), specially when detecting ankle kinematics (Eltoukhy et al., 2017; Llorens et al., 2015), and limited depth range, their use for gait analysis could provide clinicians with spatiotemporal measures that could complement conventional clinical assessment.. The low-cost, portability, and widespread availability (even after being discontinued) of the Kinect v2 together with the open-access, ease of use, short duration, readiness for home-based use, and concurrent validity of the gait analysis system could promote clinical integration of these measures.

5. CONCLUSION

This paper determines the efficacy of an open-access web-based gait analysis system that uses the low-cost and portable Microsoft Kinect v2 for markerless motion tracking in a sample of healthy and individuals post-stroke. The system was able to differentiate between healthy and stroke populations and showed moderate concurrent validity with clinical scales for the stride and step time and length, step width, cadence, swing right, and second double support time, and high validity for gait speed. Although the accuracy and range of the Kinect v2 is limited, the gait analysis system could complement clinical evaluation of gait in individuals post-stroke.

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An exploratory investigation into the potential of mobile virtual reality for the treatment of Paruresis – A social anxiety disorder

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ABSTRACT

This paper describes the initial exploratory phase of developing a VR intervention designed to alleviate the problems people with Paruresis experience when they need to utilise public toilet facilities. The first phase of the study produced a virtual environment, based upon a public toilet, which would run on the widely available Gear VR or Oculus Go HMD. The purpose of this prototype was to facilitate an informed discussion with a focus group of Paruresis patients, to obtain preliminary conclusions on whether they were interested in such an intervention and whether it offered potential to help alleviate the condition. In partnership with the UK Paruresis Trust the software was reviewed by both potential users and domain specialists. Results showed that the majority of participants reported a stress response to the stimulus of the virtual public toilet, indicating that it could be effective as a platform for graduated exposure therapy. Focus group feedback, and input from domain experts, was utilised as part of a participatory design methodology to guide the priorities for a second phase of development. The exploratory study concluded that this approach offers great potential as a future treatment for people with Paruresis

1. INTRODUCTION

Paruresis is a specific type of social anxiety disorder, also known as Shy Bladder Syndrome. The individuals suffering from this disability are characterized by the fear or phobia of urinating in the presence of other individuals. It is a spectrum disorder, ranging from an inability to urinate in busy public restrooms, to, in more severe cases, the inability to use a private lavatory at home when guests are present in the house. The effects of Paruresis are tremendous anxiety, embarrassment, reclusive behaviour and social isolation which impact the psychosocial conduct of an affected person (Boschen, 2008). According to the International Paruresis Association (IPA, 2017) 7% of the global population are afflicted at some level by this disability. Avoidant Paruresis suffers from a generalised lack of awareness and understanding among medical personnel and the general public along with inadequate treatment procedures; this adds to the suffering of the patients and raises the fear and embarrassment factor, ultimately making them unlikely to seek treatment.

2. BACKGROUND & PREVIOUS TREATMENT REGIMES

Williams and Degenhardt (1954), first coined the term 'Paruresis', after carrying out an in depth survey on a total of 1419 students belonging to various colleges in New Jersey. The questions asked by Williams and Degenhardt targeted the particular social scenarios or 'triggers' which initiated the dysfunction. Their results enabled them to uncover patterns correlated with age and change in environment of the patients. Analysing the results of the survey provided with the first clear picture that Paruresis not only existed but affected people on a substantial scale.

The earliest methods of shy bladder treatment were surgery based, such as bladder neck surgery by Winsbury-White (1936), or urethral sphincter surgery by Emmett, Hutchins & McDonald (1950) approaches which were drastic, invasive and largely unsuccessful. In vivo treatment by Wilson (1973), applied 'imaginary supplanting' to help aid a college student to completely recover from his phobia of urinating in the college restrooms. The methodology involved asking the patient to urinate alone, in a safe and empty bathroom environment, but to imagine the presence of another person just as he was about commence. In a space of two weeks this test subject was able to urinate, even in the presence of others around him. The success of this study led to further work (Anderson 1977) adopting a similar methodology with 5 patients, concluding with similar levels of success. Alternative methods of treatment (Lamontagne and Marks, 1977) have utilised "flooding", the drinking of copious quantities of water prior to visiting a public toilet as a physiological stimulus to help overcome the blocking physiological response to the phobia.

For patients where such techniques failed, Ascher (1979) and Jacob and Moore (1984) developed the approach of paradoxical intention, a technique involving a patient visiting a public lavatory, unzipping their trousers and pretending they are urinating. Key to the intervention was the rule that despite their actions, they were not permitted to urinate. Repetitive exposure to this treatment resulted in reduced anxiety levels and a reduction in urinary retention. Mozdzierz (1985) was able to report a high level of success in a single participant with long term Paruresis by combining paradoxical intention with self-hypnosis. Limited interventions based upon medication have also been applied to the problem, for example Zgourides(1988) trial of Bethanechol Chloride and Thyer and Curtis (1984) trial of Furosemide, both being desensitising medications, however there is no direct evidence pointing to the potential of a drug based cure for Paruresis yet.

The current therapeutic approach is fundamentally built upon the work of Nicolau, Toro and Prado (1991), this entails the adoption of a multi-channel therapeutic approach, utilizing social intervention, cognitive restructuring and in vivo desensitization. Treatment and support for people with Paruresis is predominantly organised under the umbrella of the International Paruresis Association, in particular though workshops and counselling sessions. These are structured programs incorporating specialised graduated exposure therapies (GET) as a component within a programme of Cognitive Behavioural Therapy (CBT). In addition to the workshops, there are support groups and online discussion forums for information and experience sharing. They also provide information about existing drug therapies and support extended research into exposure therapies. The partner in this project, The UK Paruresis Trust is a registered charity providing these therapeutic workshops in the UK, along with workshops and support groups. They are also active in increasing awareness of the condition amongst medical professionals and the general public and promote consideration of the requirements of people with Paruresis in the design of public conveniences.

3. AIMS

The hypothesis underpinning this project is that a virtual environment simulating a public toilet can be utilised to increase arousal in people experiencing Paruresis. Evidence of an anxiety response in association with exposure to a simulated environment would thereby point to a future potential use of a virtual environment as a form of exposure therapy to help mitigate the condition.

Despite an exhaustive literature search, it appears that there has been no prior work in this area to investigate the potential application VR has as a therapeutic medium in the treatment of Paruresis. Such a finding is somewhat surprising, particularly when considered against the widespread prevalence of the condition, and the debilitating nature of the ailment. The previous lack of interest in this area is also noteworthy when examined from the perspective of the extensive body of literature covering the application of VR Exposure Therapy to a broad range of phobias, social anxiety, and mental health conditions (Valmaggia, Latif, Kempton & Calafell, 2016).

To help investigate this hypothesis two key aims were identified, the first was to consider the possible hardware platforms and software approaches which could be brought to bear upon this problem. The second aim sought to prototype an initial VR solution. The purpose of this prototype development was primarily to facilitate informed discussion in a focus group context, allowing genuine participant input into the direction and design of subsequent iterations. A secondary role of the first developed prototype was to evaluate the user experience and to obtain preliminary results indicative of increased anxiety levels, paralleling the real world experience of somebody with Paruresis. Such a result would thereby support further work, informed by participants, to refine and improve the virtual environment based upon user input.

4. DISCUSSION OF POSSIBLE VR APPROACHES

It was clear to the authors that VR technology offers great potential in this field, and several potential pathways which could alleviate the symptoms of the condition are apparent. In one scenario, the availability of low cost, portable VR systems could be deployed in the role of distraction therapy (Weiderhold, Gao and Weiderhold, 2014). In this context one could imagine somebody with Paruresis closing themselves off in a toilet cubicle utilising the headset and headphones to block out the triggers of the anxiety, replacing them with visual and auditory stimuli which are more comfortable, familiar, or psychologically sedating, than the real world environment they are situated in. VR Experiences such as "*Zen Parade*" (Mack, 2018) might be particularly effective in this context. Such an approach is very much a "Sticking plaster" solution, as it could provide a method of overcoming the symptoms of the ailment without any attention to the root cause. It would however be quick and easy to pilot at low cost using currently available hardware and software.

Of more interest, and the subject of this paper, is the potential to utilise VR in the context of CBT, specifically the potential offered by VR as a form of exposure therapy. Current in vivo treatment regimens are encumbered by several limiting factors. Initially there is an embarrassment threshold to overcome; People seeking treatment are required to disclose that they are suffering from a condition that they may regard as very personal and private. A VR solution would permit anonymity, both in the acquisition and the utilisation of the software. There are also issues of availability. In vivo treatment is limited by spaces available on a therapeutic workshop, and despite the best efforts of the relevant charities, when the prevalence of the condition is considered it is clear that face to face therapy will ultimately fall short of universal accessibility. Furthermore, improvement substantially depends on the individual carrying on the graduated exposure after the workshop; this is difficult for most due to the lack of availability of scenarios suitable for the stage the individual is at. Finally there are the cost implications. For some people this is a minor consideration, particularly when looked at from the perspective of the liberation that overcoming the condition brings. For others however the costs of treatment may be prohibitive, or for individuals at the less extreme end of the spectrum, may simply not represent a reasonable value proposition. It seems clear that utilising VR exposure therapy is a convenient and cost-effective potential solution, offering the possibility of greater capacity/availability and lower cost than existing in vivo approaches.

A closer examination of the specific nature of the VR experience falls into three distinct possible categories. 360 degree immersive video could be utilised. This would enable a high fidelity rendition of a toilet facility to be reproduced without a substantial investment in 3D modelling or programming. Prearranged scenarios incorporating a range of anxiety triggers could be storyboarded, and actors could perform the role of agents and avatars. There are some foreseeable problems with this approach, the prevalence of mirrors and reflective surfaces in toilet facilities permitting participants to see the technical equipment, or observe a "false" avatar. Obtaining the necessary ethical clearances and questions of privacy and decency were also identified as potential problem at this stage. It is however a concept that the researchers are keen to return to.

There is also a very clear role which augmented reality could fulfil in this context. This could offer the opportunity for the participant to relieve themselves in a natural manner, whilst augmenting their perspective of the toilet facility with computer generated humanoid agents. Such agents could be configured so as to facilitate a controllable stress response, based upon factors such as their level of realism, their proximity to the participant, or their behavioural actions. Recent SDK developments such as Apples ARKit or Googles ARCore make such a system feasible to develop. Whilst there are some complex implications associated with anybody wearing a head mounted display in a public toilet facility, it remains an approach which could be deployable in a controlled setting, such as at home or "out of hours" access at a workplace. It may also be viable to maintain an accurate "target" for toileting purposes whilst overlaying a full computer generated toilet facility, particularly of smaller spaces such as plane or train toilets, or individual cubicles.

An alternative, and the form of VR trialled in this study, is a simulated 3D environment produced using 3D modelling tools and made immersive and interactive through the utilisation of the Unity Game engine. The interactive nature of this kind of simulation offers enhanced potential to tailor the experience to meet the specific needs of different groups of users. Offering the ability to interact with the environment also enhances the degree of presence, known to be a factor predicting a successful outcome for VR exposure therapy (Price and Anderson, 2007).

5. METHODS

5.1 Equipment

The low cost Oculus based Samsung GearVR was selected as the head mounted device. This operates in combination with any Samsung Galaxy S series phone.The device costs approximately £50, so is a relatively inexpensive platform, a key factor when considering the potential for widespread adoption. It is also the highest sold, advanced consumer VR device of all time with over 5 million units in circulation by the start of 2017 (Batchelor 2017). This platform is therefore a mature and viable test bed for a potential rollout of the system. It is also worth noting that the development methodology employed, in particular the utilisation of the Unity Game Engine, means that the application developed is somewhat platform agnostic. The software is fully compatible with the recently released Oculus Go headset and deploying the existing codebase to Google's Daydream VR ecosystem to make the therapeutic software available to an even broader audience is a relatively trivial step.

5.2 Selection of Participants

From the outset it was determined that, given the pioneering nature of the work, the participation of people suffering from Paruresis and those who are experts in the field would substantially improve the trajectory of the work. Discussion with Dr Steven Soifer of the International Paruresis Association (IPA) led to a meeting with the UK Paruresis Trust (UKPT) and after multiple follow up discussions, the board of trustees enthusiastically agreed to collaborate with the facilitation of the study. Time was allocated during a residential weekend workshop organised by UKPT, and participants at the workshop were able to volunteer to take part in the VR experience and focus group.

5.3 Metrics

A decision was made to use the Shy Bladder Scale (Soifer, Himle and Walsh 2010) to quantify the level of Paruresis in the patients. This questionnaire provides a simple benchmark to help understand the profile of the focus group participants. At this stage it was not intended that this assessment would be further analysed against the feedback responses of participants, though for future work the Shy Bladder Scale could provide a measure against which any alleviation in symptoms could be measured.

Since anxiety is a relatively subjective experience, it was determined that a validated questionnaire tool which could more clearly quantize the anxiety continuum would be adopted. A ten point version of Wolpe and Lazarus's

(1966) "Subjective Units of Distress Scale" (SUDS) was utilised. Participants were asked to indicate an integer on a scale of 0 (no fear) to 10 (severe distress or incapacitating fear). The SUDs is frequently used in exposure therapy based studies as it is easy to explain to the patient, does not require any elaborate answering and easy to identify various levels of fear associated to the disability. In the context of this study we asked participants to complete the SUDS questionnaire twice. One questionnaire was completed immediately prior to using the simulator, and another immediately following the removal of the HMD. A change in scores therefore implies a psychological impact attributable to the experience of using of the virtual environment.

Qualitative feedback was gathered through a 30 minute focus group involving all the test subjects. This was designed as an open ended, facilitated discussion, to gather their opinion and feedback about the potential of a VR intervention as a treatment. It also sought to assess the suitability of the commercial HMD, and comments about the existing features of the prototype software, with suggestions for changes and additions which could be incorporated into the next development iteration. This approach should be viewed in the context of a user centred, or participatory design methodology where the initial prototype serves to focus discussion and facilitate concrete, informed opinion, guiding the priorities and trajectory of the second development iteration.

5.4 Description of the Trial

Nine participants present at a UKPT workshop volunteered for the VR trial. All were male with an age range of 22-60 years and a median age of 34 years. The Shy Bladder Scale (SBS) was used as a tool to rate the severity of Paruresis experienced by the participants. Out of a maximum achievable tally score of 76, patient scores ranged from as low as 28 to as high as 63. The Median score for the group was 49, with most patient scores falling within the range of 40-50.

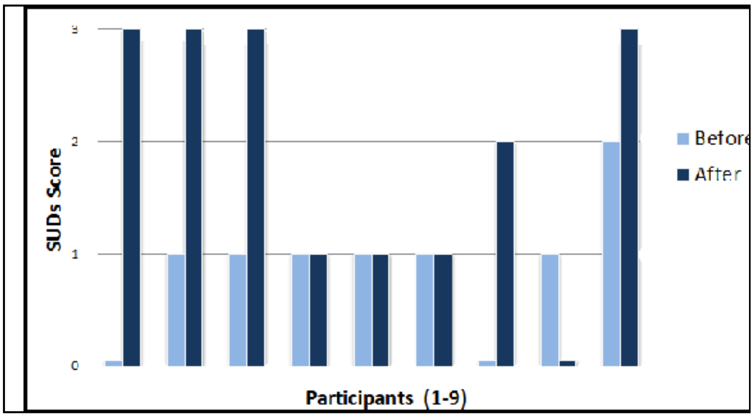

Figure 1 – SUDs Scores pre and post use of the virtual environment

The procedure involved the participant wearing the Gear VR HMD, noise isolating headphones and holding a wireless motion controller to track hand movements. The design of the simulation placed the participant in a virtual public restroom. This incorporated factors designed to induce manageable levels of anxiety for people with Paruresis i.e. presence of another human being, footsteps, or talking. It was intended that these could form a controllable exposure level, so factors which are liable to have a higher anxiety inducing effect can be controllably and gradually introduced as the patient's sensitivity decreases. Mechanisms to achieve this under the control of the participant or under the control of the researcher / facilitator were explored. Ultimately, to simplify the testing sessions a mechanism of gradually increasing severity triggers was used for this pilot study, with participants instructed to remove the headset if they found the level of anxiety induced to be excessive. The test session lasted up to 10 minutes, though participants were instructed that they were free to shorten this duration in accordance with their own comfort or level of interest.

Interacting with the first cubicle teleports the patient inside the toilet in a seating position and introduces an audio clip that creates presence of one or multiple individuals in the toilet adjacent to it. Interacting with the second cubicle does the same action as the first but puts the user inside the body of a static avatar sitting on the toilet. The differing approaches were intended to help facilitate a discussion about the importance of an avatar representation within the environment.

Patients were advised to spend a minimum of 2 minutes inside the cubicles in order to experience the range of triggers set up for the experience. They could however leave at any point by taking off the headset or focusing their gaze upon the cubicle locks which would facilitate an interaction to exit the cubicle, returning the patient to the starting coordinates in front of the wash basin. The application also gave the user a choice to teleport to the urinal, where triggers of adjacently standing human avatars and audio cues are. The user is allowed to turn, gaze and interact with the hand dryer whenever they wish to return to the starting location. The software developed incorporated both female and male toilets, with the user free to pick which door they went through. The single sex nature of the focus group meant that ultimately only the male version was trialled by potential users.

6. RESULTS & EVALUATION

The initial hypothesis was that exposure to the virtual environment could increase the arousal in people who experience Paruresis. Evidence of an anxiety response in association with exposure to a simulated environment could thereby support a future potential use of a virtual environment as a form of exposure therapy to help mitigate the condition. One of the objectives of the testing phase was therefore to obtain a measure which would support the potential utility of a virtual environment being deployed for the purpose of desensitisation. For any VR exposure therapy to be effective it is important that the user is psychologically engaged to the extent that there is suspension of disbelief and some degree of cognitive association made between the virtual world and the stimulus it purports to reconstruct. For this initial study we utilised the SUDS scale, looking for a rise in reported anxiety. This may seem at first glance to be counter intuitive, as the ultimate goal is the reduction of distress. In this context though, a measured rise in anxiety is indicative of the simulated environment promoting an analogous response to that which they might experience when visiting a real public toilet.

When comparing a mean average of before and after SUDS scores, a total of nine patients showed a pre exposure mean anxiety score of 0.89. A similar mean average for the post exposure scores show a reported rise in anxiety, with the score reaching 1.89, so a mean increase of 1 step in the SUDs scale is reported. Applying a t test to these results yields a P value of 0.036, so statistically speaking the response is significant. That said, the sample size is small, and in this context the aggregated statistical results perhaps reveal less than can be inferred from an individual appraisal of each participants own scores. Looking more closely at the results five patients showed a clear rise in post exposure anxiety scores, while 3 showed unchanged scores and one patient recorded a lower anxiety score. It should be noted that the highest recorded SUDs score is 3, in both pre and post-test phase.

The results recorded from the SUDs are encouraging however care is needed in terms of interpreting the results. As more than half of the participants experienced the desired reaction from the use of the software, is can be implied that extended trialling of the software with this sub group is likely to yield interesting results. It is possible that this sub group finds it easier to quickly achieve psychological immersion, or that the stress cues present in the environment were more acute triggers for these individuals, accounting for a response. For the subgroup reporting no increase in anxiety it is possible that they did not achieve psychological immersion, that the environmental triggers were not in alignment with their own stress factors or that the triggers were not convincing enough to elicit an anxiety response. It is of course also possible that some participants were very slightly anxious about experiencing VR or participating in the study, and these confounding factors, which would amplify the pre-test score are a key limitation of this part of the study. It is possible that this interpretation explains the scores of the participant whose anxiety was reduced after using the simulator, and, if this factor was significant overall its impact would be to downplay the potential effectiveness of the simulation in eliciting a stress response.

The key intention of the study was to engage potential users of the software and to offer all participants in the study the opportunity to comment upon the first prototype, and to have input into the design and feature priorities of the next iteration. The focus group commenced by talking about the visual fidelity of the environment. One of the patients stated, “The quality of the structure was enough for me to believe I was actually there”. The participants were all broadly in agreement with this point, and there was a generalised view that “realism” was an important factor in triggering their anxiety levels. This discussion of “realism” highlighted an issue with the interaction mechanic, of providing a colour change visual cue to highlight to the virtual objects which could be interacted with. This “unrealistic” mechanic was, with the benefit of hindsight, unsuitable for incorporation into an exposure therapy simulator where believability is central to success.

When questioned about the priorities for improving upon the prototype, the key feature requested was the incorporation of “other people”. Whilst the simulation did in fact contain a representation of another person, these are such a key anxiety trigger that the lack of believability in the humanoid models utilised was immediately noted. It was therefore deemed to be important to incorporate high fidelity animated human models into the environment for future iterations. On the subject of avatars it is interesting to note that a preference was expressed for no avatar, rather than the self-avatar, after users had experienced both approaches.

One of the key issues discussed was the limited peripheral vision due to hardware restrictions on the Gear VR headset. For example, an agent urinating in the adjacent urinal couldn’t be noticed unless the user turned their head around. A patient stated, “Peripheral vision, the way we are able to see 180 degrees without turning our head, I felt that was missing from the VR application because VR can’t produce that”.

Several users questioned the exclusion of free movement in the environment, a patient enquired, “Don’t you think that being unable to move freely is an issue?” When the rationale for limiting movement in this prototype was explained they felt it was a reasonable feature to exclude from the environment, and it did not affect the primary functionality of the application. However the desirability of making the environment more explorable was noted and the potential of 6DOF mobile VR, such as that offered by the Oculus "Santa Cruz" could potentially facilitate this.

Finally, the focus group were not overly encouraging about its potential as a standalone treatment, being more supportive of its potential as adjunct to the existing workshop. As one participant stated "it would be a great option for patients to utilize it on their own between Cognitive Behavioural Therapy (CBT) workshops organized by the UKPT." One of the patients said, "I think we should start off by reading Steven Soifer's book in order to identify the problem. I'll definitely agree that this VR therapy is more effective for severe patients, like I was 12 years ago". An expert present, and a trustee for UKPT, stated, "I don't think that this VR exposure therapy can cure Paruresis by itself. However we can train our patients to use this in combination with Cognitive Behavioural Therapy. It will also help them by introducing a self-training programme to gain better control in the early stages".

In terms of priorities for new environments to be developed, toilets based upon those found in airplanes and trains were highlighted as the most useful alternative environments to now focus attention upon. Reference to the impact upon freedom to travel experienced by people with Paruresis is present throughout the background literature, and with hindsight would have been a good starting point for the first prototype. This finding perhaps serves to reinforce the value of consulting with potential users at the earliest possible opportunity, and is already informing the path of ongoing and future developments.

In the weeks following the focus group five of the participants contacted the researcher, expressing an interest in future involvement with the project and reviewing future prototypes. One participant stated, "I have a Gear VR at home and if you can build something more specific for the triggers that affect me, please let me know"

Figure 2. One of the UKPT trustees testing out the VRET

7. CONCLUSIONS & FUTURE WORK

While the existing results are preliminary and tentative, they are nevertheless encouraging. There is good evidence that the initial hypothesis is well founded, and that a majority of users experience some stress response in association with the experience of being present in a virtual public toilet. There are also several technical avenues identified utilising VR technology which are worthy of further exploration and evaluation, with the likelihood that a portfolio of different experiences and approaches will ultimately be shown to have value in this context. There are however some significant issues which ultimately need to be addressed. The view of the users was that VRET software has a lot of potential to be used in conjunction with CBT and should not be considered as a complete replacement to present cognitive therapy techniques for treating Paruresis. This finding somewhat tempers the potential of an anonymous, self-administered therapeutic virtual experience envisaged at the outset. From a technical perspective mobile VR using the Samsung GearVR has proved acceptable in terms of low cost and environmental believability. However, there is a key limitation in terms of lack of peripheral vision affecting the perception of participants. This is particularly notable in the key context of standing at a urinal with somebody adjacent. While extremely wide field of view headsets such as Star VR or Pimax could resolve this, it would currently come at the cost of the low cost, and ease of access, offered by Mobile VR technology.

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Towards transformative VR meditation: Synthesizing Nirvana naturally

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ABSTRACT

Therapeutic VR offers the ability to deliver a safe, reliable and protocol-driven analogue of mindfulness-based stress reduction (MBSR). When conducted according to inclusive design principles that heed aesthetic principles while being mindful of the psychophysics of perception, it may well be possible to offer a transformative rehabilitative experience that makes few demands of the patient/participant beyond an invitation to feel grounded in an immersive state of Being and Time. Working primarily with 3D imagery "naturally" captured employing a 7-camera GoPro rig we have constructed a naturescape of the northern Alpine region in a 3-year project entitled "Windows to the World", funded by the Social Sciences and Humanities Research Council (SSHRC), with anticipated completion in the coming calendar year. This apparatus has been augmented with the composition and production of 3-D spatialized audio intended to evoke feeling-states of calmness, equanimity and a profound sense of wellbeing, for example, analogous to enjoying a relaxing sunset or sunrise while on a vacation. To this end, it may well be possible that such meditative experiences could confer powerful transformative experiences of wellbeing and leisure.

This project conceptually builds upon established evidence that engagement with geophysically real naturescape environments such as mountain resorts confers physical and mental wellbeing for participants (e.g., the elderly, especially if frail or disabled) in addition to the fact that many dwellers of urban environments are limited in their capacity to physically journey to such destinations due to constraints of time, opportunity, ability and financial means. In this theoretical and methodological framework to inform our VR therapeutics endeavour going forward, we have chosen to focus on the Northeastern European Alpine region as a case study of a putative simulated *"wellbeing environment"* modelled upon a naturally occurring landscape. This is based in part upon a historical and psychogeographic research approach which considers also environmental mental health interventions that might have been employed with success in an era of medicine prior to the advent of current conventions (i.e., treatment with psychopharmacologic agents) though human-environment interventions (e.g., removal of immediate stressors, meditative contemplation, a rejuvenating rest-period, etc.). By allowing supervised exposure to meditative naturescapes such as majestic mountains, we seek to expand on earlier clinical research demonstrating the efficacy of protocol-driven VR-based MBSR for optimal wellbeing when employing synthetically generated, yet naturally experienced wellbeing and leisure states.

1. INTRODUCTION

"Presence" is a psychological construct in which an individual feels a sense of "Being" in a particular environment, whether they are geospatially in this location or not (Moller & Barbera, 2006, Waterworth et al., 2018). VR has gradually emerged as a societally relevant and game-changing multidisciplinary manifestation of many of the academic prophecies of Canadian media scholar Marshall McLuhan, who in the 1960's prophesized a connected multicultural "global village" where "the medium is the massage" (McLuhan & Fiore, 1967: the actual original title of this writing, though now most commonly cited as "the medium is the message") and technology allowed a melting of barriers posed by the nature of our being in space and time (Heidegger, 1962). Historical models of healing that have sustained individuals, communities and populations, though surprisingly similar in essence throughout the world, are not always readily addressed within conventional biomedical or managed healthcare schemas. It may be worth re-examining some of these older healing models, as enlightened clinicians and researchers navigate towards sustainable future-oriented models that allow for the creation of transformative health journeys respectful of our innate human nature. This notion created the imperative to "Windows to the World", a 3-year project funded by the federal Canadian SSHRC agency, which is currently in progress.

Meditation is increasingly *en vogue* not only in medical/psychological settings, but also as a self-care or lifestyle approach that promotes resilience, quality of life and wellbeing. As a parallel phenomenon, the re-emergence of holistic health-care models is highlighting the value of nature-based environments in healing and personal transformation. In this paper, we explore the internally experienced world of a VR-based meditation program constructed based on externally derived natural environments used in a health-care setting. To this end, we are designed what is essentially a "built environment of the mind" that incorporates multimodal display of a majestic naturescape experienced immersively, comparable to, e.g. a dream, reflection or memory.

Interventional built environment research has typically focused on the physical geospatial design of urban spaces, e.g., for encouraging physical exercise (Kazynski and Henderson, 2007). However, exciting research developments have emerged demonstrating that multimedia-based immersive virtual environments can authentically simulate real human conscious experiences (Fox et al., 2014). The existence of mirror neurons (Heyes, 2009) shows that people can develop internal models of experience, and the finding that imagery (imagined experience) recapitulates the perceptual analyses associated with actual sensory experience (Laeng and Teodorescu, 2002), provide a powerful motivation for the use of virtual reality experience of majestic mountain ranges in place of the real thing for therapeutic or recreational purposes.

"Leisure", or perceived freedom is an underappreciated enabling as well as chief limiting factor to wellbeing (Moller et al., 2014). This reality is not always readily addressed in conventional biomedical approaches and challenges us to look to both to the past and future to inform our present. Patients with stress- and/or anxiety-related ailments, when asked to re-imagine a recent "wellbeing experience" at a time they might have not felt a sense of malaise or distress frequently report holiday vacations as a source of solace. However, while the anticipation and ensuing preparation for a get-away (as well as the sojourn itself) is often cited as a reprieve from stress and worries, a sustained duration of this wellbeing effect beyond a week was rarely observed. Not infrequently, souvenirs, novelties, artefacts, photographs or other memorabilia are employed by leisure-seeking tourists, usually in an unstructured and idiosyncratic manner, to re-imagine the (hopefully) positive experience and re-inspire the seekers of inspiration and wellbeing in their routine everyday lives. We seek to extend the historical and cultural legacy (Kevan, 1993) of the mountain sanatorium health retreat to digital media interventions that can potentially provide similar benefits at less cost, and less disruption to the rhythms of modern life. To this end, the fundamental question being asked is: "*How can leisure experiences that enhance quality of life and wellbeing be made accessible through immersive VR experiences that do not require (often expensive) travel to remote physical environments?*" A secondary query then pertains to how one might optimize these on in terms of aesthetic appeal, impact and resonance.

Employing the Northeastern Swiss Alpine region as a case study, we seek to address the public policy imperative of equitable access to wellbeing environments such as mountains or the seaside in terms of leisure opportunities and constraints in an increasingly socioeconomically divided and urbanized developed world. We look to supplement earlier approaches to handling stress and malaise through visits to therapeutic (natural or artificial) environments with the use of therapeutic immersive VR. We also seek to explore perceived authenticity, impact and resonance of our "built environment" based on preferences in aesthetics to clarify aesthetic preferences of "naturally" captured naturescapes (shot using 3D film) in comparison to gradations of "synthetically" created computer generated imagery (CGI). We adopt an industrial engineering approach to the goal of recreating leisure (Moller et al., 2014) and wellbeing experiences, and focus on immersive media technologies, i.e., virtual reality environments (VRE) as therapeutic interventions (Bohil et al., 2011), while remaining mindful of trends in mental health-care involving meditation/MBSR.

On a more historiographic and psychogeographic level, we are interested in better understanding the mental health effects of a VR simulation of a journey to an environment with an established reputation for conferring wellbeing on the ailing: e.g., an Alpine mountain environment, as eminent central European writers of the maturing industrial age such as Thomas Mann or Hermann Hesse might have approved of as remedies in times of physical and/or emotional weakness and lassitude (Mann, 1924, Hesse, 1925, see figure 1). Beyond these examples of classic romantic autoethnographic literary research, there is indeed hard evidence of the northern Alps being sought out for the mountain range's restorative effect on physical and emotional wellbeing. To highlight an example more specific to our case study, at the site of Bad Ragaz, CH, a seemingly magical mountain stream was discovered in the narrow, plunging Tamina Gorge near the current Swiss-Austrian border region (Senn, 1993). Here, in the early middle ages, monks employed the body-temperature stream gently flowing through the deep mountain gorge to perform what were perceived as healing effects on rheumatic, infectious and spiritual ailments by exposure to a transformative natural environment. This eventually led to the establishment of a healing sanctuary attached to a monastery by the mid-16th century, inspected and touted by Swiss physician and philosopher Paracelsus, a major forefather of modern biochemical western medicine (Senn, 1993). European doctors practicing medicine in urban centres around the end of the 19th century Victorian era increasingly recommended "the mountain cure" (or in other cases, "a little time away by the seaside") to patients with ailments within this spectrum, with a recognition that redemption for the illness-inducing miasmas of city life might be a retreat to the refreshing mountain air of the Alps paired with healing springs. With an evolving industrial revolution, however, came also recurrent, and at times, escalating periods of social unrest and growing economic disparities. Access to such places of nature, wellbeing and leisure soon became scarce once more, as it continues to be for many in not only Europe, but indeed, within a globalized, largely urbanized global village, with many less well-to-do urban dwellers finding themselves priced out of the nature sanatorium market alongside other sources of wellbeing, a phenomenon that continues to persist within the developing as well as developed world (CIW, 2012).

Figure 1. *Victorian era depictions of invalids and urban industrial age escapists seeking refuge and healing at the therapeutic mountain sanatarium health refuge at Bad Ragaz, CH, for conditions such as tuberculosis and rheumatism as well as for enhanced mental wellbeing, popularized by Romantic writers such as Thomas Mann and Herman Hesse.*

2. METHODS/APPARATUS

We are employing a VR system that was developed at PRAXIS Holistic Health to capture and display/ communicate the required content (consisting of audiovisual content captured via immersive technologies as described in the following section) to create a "leisure and wellbeing environment" for immersive presentation. In brief, to date, three exploratory 3-D video data capture sessions have taken place on location at Mount Saentis and Bad Ragaz (Switzerland), and Feldkirch (Austria). Audio was subsequently composed and produced, using 3D spatialized sound at Tileyard Production Studios (London, U.K.).

2.1 General concept

We have separately produced video and audio content, with the former being filmed "live", and the latter being conceived, composed and produced separately for subsequent fusion into a unified AV experience to be consumed perceptually in experimental and therapeutic context. We are using a ca. 30-minute audiovisual display, congruent with the approximate length of a cycle of rapid eye movement (i.e. REM, dreaming) episode in the course of a night of healthy adult sleep (Moller & Barbera, 2006). As outlined in a recent review of neurophysiologic aspects of presence and immersive experiences by our group (Waterworth et al., 2018), we remind that consciousness is dynamic and fluid even during wakefulness, however, more stereotyped and phasic during the largely subliminal process of sleep, which also shows characteristic variations throughout the human lifespan. Using this framework, it is within REM dreaming's "protoconsciousness" that perceived perceptual stimuli are sorted through and ultimately stored or deleted via more enduring memory shelving and retrieval, i.e. the basis of transformation within a perceptual experience (Hobson, 2009). We propose that it is through this dynamic and largely subliminal process that the process of psycho-emotional transformation may occur to a large part, with the both declarative and nondeclarative memories created to create a change in consciousness.

2.2 Apparatus

Each filming session involves verifying identical settings on 7 GoPro HERO4 BLACK cameras unless exposure compensation is required (see figure 2). A wireless remote triggers the mounted cameras, an audio marker is added, then the cinematographer(s) seek cover. Battery life is doubled with USB powerpacks trickle-charging the mounted cameras. Unprocessed video averages 45 mins to 1 *1/2* hours.

Figure 2. *Camera rig*

2.3 Post-Production

The editing process consists of preparing each camera's video files; synching, stitching, horizon and colour correction in the Kolor panoramic software suite; stylized in Adobe AfterEffects or combined with responsive 3D elements in Unity. Colour modification, radial motion, particle clouds, and strobe light effects are implemented. (See also Section 3.2.2 and figure 4).

1. Colour modification – an emerald hue exaggerates the foliage and sky
2. Radial motion – a twisting wheel or vortex adds entrancing forward motion
3. Particle clouds – billowing clouds create random ambient motion on still shots

Strobe light – undulating light frequencies control entrancement

2.4 Audio

Audio content was composed based on principles of correlating tempo of a variety of instrumental classical music pieces presented in a continuous mix with electroencephalographic (EEG) frequencies associated with states of inspiration, calmness and tranquillity (See figure 3). This was based on understanding of brainwave frequencies associated with alpha-EEG (approximately 8-12 Hz or beats per second), representing calm awareness, theta-EEG (4-8 Hz), representing reflective and evocative dreamlike thought processes as in rapid-eye-movement (REM) sleep, and delta-EEG (1-4 Hz), most typically experienced as deep, dreamless and restful sleep (Rechtschaffen & Kales, 1968). This, in contrast with conventionally experienced wakefulness-related beta-EEG frequencies of (12.5-25 Hz). The intent is to deliver immersive HQ audio content aimed at entraining the participant's consciousness state towards alpha, theta and delta oscillations, congruent with the sub- and unconscious in accordance with the rhythmic flow of selected ambient and classical music recognized to possess potential properties to entrain alpha- and –theta EEG (Kabuto et al., 1993, Klimiesh, 1999).

3D *Audioscape* software was used to finalize audio production, allowing a combination of level panning and first order ambisonic processing to create hyper real audio environments in 3 dimensions (left/right, front/back and up/down). This software employs a virtual model of an actual physical space, so any movement in the virtual space is replicated in the actual space. The software has 16 monophonic inputs, which can be paired to accommodate stereo, and each input can be moved around independently on any given axis, allowing sounds to be placed or moved around anywhere in the space. The spatialization is controlled by midi controller vales, allowing it to be recorded and edited/manipulated in any modern digital audio workstation. This midi information can be generated by any midi controller and/or 3D joystick, as in the type used for gaming. This runs via the software *Junxion 4* which converts the joystick movement into the relevant midi values. The spatialized audio can be played back in any environment and decoded to whatever speaker array is being used, including binaural (HQ headphones) or multi speaker arrays.

2.5 Delivery

The panoramic video is then delivered locally through a HTC Vive headset running GoPro VR Player on a gaming computer, paired with spatialized HQ audio on headphones. YouTube streaming quality restrictions indicate remote content delivery requires a more aggressive buffering or pre-caching schema to meet user expectations. To assist in inducing a state of calm relaxation congruent with rest and convalescence, individuals will be reclining in a supine position with head slightly elevated on a comfortable cot or reclining chair during the entire meditation experience, which will last ca. 30 mins (coincidentally, the approximate duration of an episode of REM or dreaming sleep during consolidated healthy sleep (Aserinsky & Kleitman, 1953).

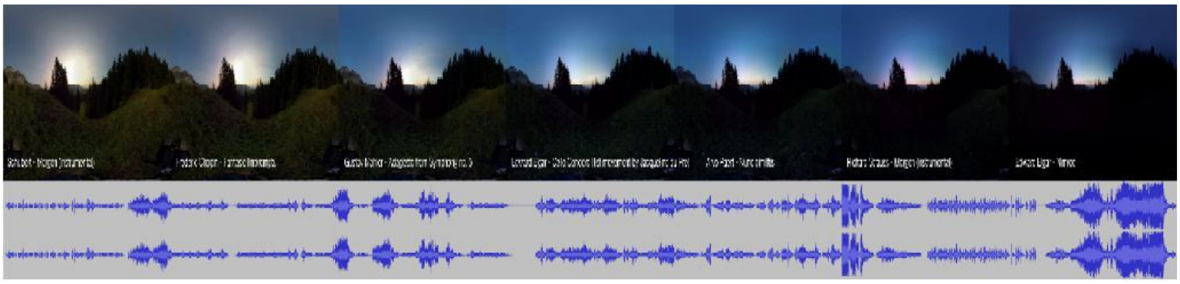

Figure 3. *Dusk to-night-panoramic Alpine sunset video (captured at Mt. Saentis, CH) with 7-track "Green Dragon" immersive audio mix*

3. METHODS/PROTOCOL

3.1 Objectives

Our research project has the following objective and will be employing a mixed methods qualitative / quantitative research approach to explore our research objectives.

(i) Assess the relationship between leisure access via immersive reality, and resulting measures of QOL, wellbeing and global mental health,

(ii) Development of a set of physical leisure environments (i.e. Alpine environments) that are embodied as immersive reality, with quantified results concerning their enhancement of wellbeing,

(iii) Results concerning the extent to which immersive experiences, delivered through virtual reality platforms can improve subjectively experienced wellbeing.

(iv) Explore the effectiveness of video only immersive reality (VOIR) vs. gradations of computer generated imagery (CGI) annotations as interventions to improve subjective wellbeing through the presentation of uplifting environments.

3.2 Subjects

3.2.1 Clinical/psychological evaluation group

Once ethically approved, 20 consenting and informed clinical adult subjects with anxiety conditions, (M/F, aged 1865, residing in urban and/or suburban region of Toronto), drawn from the PRAXIS Holistic Health clinic will be offered participation in a prospective naturalistic observational study involving exposure to our intervention under two conditions: immersive VR versus standard comparable AV stimuli. To qualify, subjects need to exhibit objectively validated levels of clinically significant anxiety (as evidenced by a Beck Anxiety Inventory [BAI] score of 10 or greater, Beck et al., 1988). As this is a naturalistic study, comorbid medical ailments will be allowed for (though documented). Exclusion criteria are: psychotic illness or dementia (reality distortion potential), epilepsy, pregnant females and significant perceptual apparatus pathology (ophthalmic, auditory, vestibular—potential for simulator sickness). Demographics including age, education, marital/parenting status, occupation and cultural/ethnic background are to be noted. Additionally, an individual participant's prior experience with psychiatric intervention as well as meditation approaches to health and wellbeing (both didactic and autodidactic) will be noted, and the standard medical wellness assessment clinic intake form used at the PRAXIS Holistic Health clinic will be employed at time of entering the research study, allowing, if necessary, identification of medical and psychiatric pathologies (extrinsic factors outside the scope of the research question being addressed) that might modify the experimental results. Subjects will be exposed to the intervention for approximately 30 minutes at a time, with pre- and post-intervention data gathering, both quantitative and qualitative. The intervention is to be repeated again at t= (1 week) and t= (2 weeks) in a similar fashion.

Figure 4. *Four visual effect scenarios to be used to evaluate aesethetic preferences*

3.2.2 Non-clinical evaluation group

A second group of fully informed and consenting *healthy* 20 adult subjects will be recruited from University of Toronto using posted flyers on campus noticeboards (both in hard-copy and electronic forums). The purpose of this study will not be strictly clinical but to assay personal preferences in fidelity of visual scenarios, ranging from unaltered 3-D film to three gradations of CGI special effects, i.e. from "natural/real" footage to "synthetic/surreal" (see Figure 5 on left). These four perceptual conditions will be presented via two separate configurations:

(i) displayed using HMD and HQ headphones (encumbered, immersive VR).
(i) displayed on 70" LCD screen and external ambient speakers (unencumbered, augmented reality AR)

3.3 Baseline wellbeing

Beyond the BAI (as outlined above) baseline psychometric data will be ascertained from subjects to further psychologically characterize wellbeing and characterize possible comorbidity including: Beck Depression Inventory (depression, Beck, 1988), Athens Insomnia Scale (insomnia, Soldatos, 2004), Epworth Sleepiness Scale, (excessive sleepiness, Johns, 1991) and the WHO-5 Wellbeing Index (medical wellness, Topp et al, 2001, Bonsignore, 2005). These will be administered in order to account for complicating factors such as mental illness or sleep pathologies that might play a role in mediating an individual's receptivity and ability to fully immerse him/herself within the experience offered within this methodology.

3.4 Pre- and post-exposure metrics- (Quantitative)

Our previously validated 5-item Wellpad scale of subjective wellness (pain, mood, perceived external stress level, perceived internalized relaxation vs. anxiety and sleep quality, each quantified on a 5-point Likert sliding scale) will further seek to quantify baseline medical wellbeing (Moller & Saynor, 2016). We will add additional items assessing levels of (i) inspiration, (ii) hopefulness and (iii) perceived performance task readiness ("How ready are you to perform the tasks and demands of your daily life?") using a 5-point Likert scale, similar to the Wellpad scale. In the true spirit of human factors industrial design, this will allow utility of measuring not merely aspects of wellbeing but also productivity in an employment or educational performance-based setting.

3.5 Post-exposure experiential analysis

Aside from metrics assaying individual psychological/medical wellness, we are interested in better understanding the interface of the person-environment dyad relating to our paradigm, using both quantitative and qualitative assays.

3.5.1 Quantitative

Beyond the before and after psychometrics outlined above, we seek to parcel out the experiential subjective ratings of: (i) perceived aesthetic appeal, (ii) immersion/lucidity and (iii) resonance/impact of the experience (using a tablet-based easy-to-use 0-100% sliding scale), which will be evaluated immediately following each exposure to the experience. While we do not anticipate simulator sickness of any significance, as subjects will be resting in a supported supine position during the immersive experience exposure, as opposed to engaging in "real-world" ambulation or engaging in autonomous core body or head motion. The gold standard brief screening questionnaire for simulator sickness, namely the Simulator Sickness Questionnaire (SSQ, Kennedy et al., 1993) will be administered after each meditation session in the study.

3.5.2 Qualitative

To supplement this quantitative data, we will also be eliciting open-ended qualitative responses to questions of interest in a brief interview including:

(i) "What problems/difficulties (if any) did you encounter"? **(weltschmerz** item)

(ii) "What part (if any) of the experience do you recall?" (**sentiment** item)"What about this experience resonates with you?" "What (if any) of this experience can you apply to your real life to improve its quality"? (**resonance** item)

(iii) "Please rate on a scale from 0-100% how much you felt part of the experience." (**lucidity/immersion** item)

4. CONCLUSIONS

As outlined, the over-arching objective of this project to date has been the development and user-testing of immersive 3D VR mountainscapes intended to replicate an example of geophysical environments (mountain retreats and the like) believed to confer enhanced QOL, stress reduction and wellbeing on their visitors. According to a previously published theoretical framework based on my clinical observations of analogous immersive meditative stress-reduction therapeutics currently employed at my clinic, we also suggest that from an industrial engineering perspective, these psychological gains may translate into enhanced capacity for individual wellbeing, QOL and productivity (Moller & Bal, 2013, Moller et al, 2014). This would imply potential value in a medical, industrial or recreational setting.

In the near future, we plan an investigation regarding the optimal administration of our immersive "Windows to the World". The methodological format proposed within this article could be described as both a clinical/therapeutic trial and industrial engineering user testing. The overarching rationale for this protocol is based on classic Hippocratic '*primum non nocere' ('above all, do no harm'*) clinical pragmatism, alongside an understanding of the neuroscientific principles of sleep, wake and dreaming. Through mindful, meditative, journeys, it may well be possible to traverse the porous boundaries between states of consciousness. Our apparatus and protocol have been designed to intentionally mimic a wellness vacation experience, and we now seek to better understand it usability and impact during and directly following immersion as well as the residual effects in the short-term and intermediate time period following exposure. Unlike a real vacation, the "booster sessions" in this paradigm offer not only a non-replicated souvenir of the experience, but essentially a simulation of the actual event/experience that is sought after in order to achieve the objective of wellbeing and leisure, i.e., perceived freedom. Beyond its obvious industrial psychology application, we position our research within current clinical neuroscience models alongside the applied medical sciences model of recreation and leisure studies (e.g. CIW, 2012, Moller et al, 2017) in order to confer wellbeing to those who due to constraints of time, disability or financial means may not ordinarily or naturally have the opportunity to "get away from it all".

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Augmented rotations in virtual reality for users with a reduced range of head movement

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ABSTRACT

A large body of research in the field of virtual reality (VR) is focused on making user interfaces more natural and intuitive by leveraging natural body movements to explore a virtual environment. For example, head-tracked user interfaces allow users to naturally look around a virtual space by moving their head. However, such approaches may not be appropriate for users with temporary or permanent limitations of their head movement. In this paper, we present techniques that allow these users to get full-movement benefits from a reduced range of physical movements. Specifically, we describe two techniques that augment virtual rotations relative to physical movement thresholds. We describe how each of the two techniques can be implemented with either a head tracker or an eye tracker, e.g., in cases when no physical head rotations are possible. We discuss their differences and limitations and we provide guidelines for the practical use of such augmented user interfaces.

1. INTRODUCTION

Research in the domain of *virtual reality* (VR) has recently reached the state where inexpensive devices, such as *head-mounted displays* (HMDs) with associated rendering and tracking technologies, have become available to a wide range of users through consumer outlets. Products in this field are trying to leverage the promise of VR to immerse and engage users in a virtual experience with more natural forms of interaction than possible with other types of displays and forms of input. Typically, the user's head movements are tracked and mapped to that of a virtual camera such that they can look around the virtual world with a first-person perspective. Other forms of input include hand-held devices such as gamepads or joysticks to induce push-button rotations or translations which are widely used in many fields. In this paper, we present techniques that allow these users to get full-movement benefits from a reduced range of physical movements. Although our techniques could be applied to rotations specified via hand-based input devices, previous research has shown that user self-motion can result in an increased sense of presence [Slater et al., 1994, Slater et al., 1998, Usoh et al., 1999], and improved perception and cognition [Steinicke et al., 2013]. As such in this paper we focus primarily on head and eye movements.

While the field of VR has made steady advances over the last several decades toward becoming a useful and even ubiquitous technology for society. Developments of VR consumer products are accelerating these advances, driven to a large degree by the field of home entertainment. The vast majority of products are mainly developed by and for non-disabled persons without any limitations in motor behavior. In particular, in the field of *natural user interfaces* (NUIs), the possibility that some users may not be able to perform such "natural" interactions at all—or not to the same degree as a non-disabled person, is mostly ignored. For instance, a non-disabled consumer playing a VR game while seated on a swivel chair at home may have a full 360-degree comfortable range of interaction by rotating their head and/or body or chair, but an individual seated in a wheelchair may not be able to rotate their head to the same degree, e.g., due to motor limitations, the wheelchair's protective head cushion, or other peripheral equipment, which makes such head movements impossible or strenuous [LoPresti et al., 2003]. While people with limited or no head motion are unable to use such VR systems "out of the box," one can substitute an alternate mapping of input to virtual view control. And while there are different kinds of assistive technologies such as foot pedals, mouth sticks, oversized trackball mouse and many more [WalkinVR, 2018, Bruder et al., 2012], in this paper we only focus on using head and eye motion as input.

We present and discuss two techniques that are aimed at providing users with the ability to rotate a full 360 degrees in a virtual world, even though the range of their physical head rotations might be limited in the real world. Scenarios where no physical head rotations can be performed are also in the scope of this paper, as long as the individual has control over a range of eye movements. We approach movement limitations systematically, presenting a framework that can be used to address low or high mobility of head or eye tracking in VR, and two techniques that can be realized with NUI tracking data.

The proposed augmentation techniques are based on adaptive mappings that use (a) *continuous rotations* of the virtual world based on physical head/eye orientations or (b) *discrete rotations* that are triggered by physical head/eye orientations. Different types of eye movements, such as saccades and smooth pursuit, have varying characteristics that could induce disorienting rotations. To avoid this, developers can introduce a fixation time for gaze points that are intended to trigger the techniques. Blink patterns can also be used as triggers for the proposed techniques.

We make the following contributions.

1. We present two techniques to augment the range of virtual orientations for 360-degree interaction in VR that can be tuned to each individual's range of comfortable head/eye rotations.
2. We analytically discuss the techniques and provide guidelines for the practical use of these techniques and the use of head/eye tracking data.

This paper is structured as following. Section 2 discusses related work. Section 3 describes two techniques for augmented natural rotations. The techniques and their interplay are discussed in Section 4. Section 5 concludes the paper.

2. RELATED WORK

Many researchers have explored using VR for persons with disabilities for diagnosis, training and rehabilitation. Kuhlen and Dohle (1995) described several of these computer systems that were developed alongside assistive technologies suited for different groups of persons with disabilities. As an example, people who are paralyzed can perform tasks in the virtual environment that were not possible in the real world using assistive technologies that are capable of responding to minimum human output, which in this case was using a device that connects human bio-signals directly to a computer [Molendi and Patriacra, 1992, Lusted and Knapp, 1994]. When studying the use of VR for persons with disabilities, Ford (2001) focused on benefits that might arise by using VR with four strategies. In one of the strategies, *shift in valued functions,* he mentions that the fact that a person with paralysis cannot move from a bed does not affect their interactions in the virtual environment (VE), which can help build toward lessening alienation. Promising feedback of using VR for disabled persons led us down the path of looking into the techniques that inspired us to create a more realistic virtual experience for a user with limited head and/or eye movements, specifically being able to have a full view of the virtual environment.

One of these methods, mentioned earlier as *Continuous Rotations* was first introduced by Razzaque et al. (2002). When proposing their method, one of their goals was to eliminate the use of controllers whilst interacting in a VE, and since they used a three-walled CAVE-like immersive projection system for their experiment, they needed to come up with a reorientation technique so the user would not turn towards the non-existing back wall. In their method, a user's rotation in either direction would be followed up by an environment rotation in the *opposite* direction, with an amount determined based on factors such as the user's angular velocity.

Another technique to accomplish the goal of making the VE more accessible to the user is *Amplifying Rotations* proposed by LaViola et al. (2001), which makes viewing a full 360-degrees environment possible without using controllers. In their proposed method, since the users were able to move, they experimented with user's head, torso and waist orientation as input for the amplified rotation. They tested the method with both linear and nonlinear functions to map the input orientation to an amplified orientation. Later, Steinicke et al. (2010) formalized amplified rotations with *Rotation Gains* depending only on head movements. Sargunam et al. (2017) ran experiments using different reorientation techniques and tested factors such as spatial orientation and preference of use. They also came up with their own method of reorientation called *Guided Head Rotations* which has similarities with Razzaque et al.'s method and tries to realign the user's head orientation to a predefined forward orientation taking into account the proximity of the user to virtual objects, and the rate at which the realignment happens.

In a study mostly focused on the effects of amplified rotations, Ragan et al. (2017) ran experiments considering impacts of amplified rotation while doing a search task with the goal of exploring a 360-degrees VE. While using an HMD or six-sided CAVE, one has access to the 360-degree VE through constant rotations and movements inside that environment, which might not be ideal for many circumstances. In their experiments, they tested different amplification factors and considered effects on a user's spatial orientation and travel, search performance and simulator sickness. Their results validated the use of amplified rotations to view 360-degree VEs, noting that participants easily picked up on the new way of interacting with the environment.

As mentioned above, mapping head rotation to the rotation of the virtual camera inside the VE is not the only way of achieving a 360-degree view of the VE. There are certain types of medical conditions that greatly limit any sort of neck movement either permanently or temporarily, such as cervical cord dislocation, spinal cord injury, neck fracture, rheumatoid arthritis and many more. This gives rise to the need for another form of input as opposed to head rotations to control the view in the VE. For example, one might use bio-signals [Lusted and Knapp, 1994] or eye movements as the input controlling the full view of the virtual world. Several research groups are focused on developing new systems that are controlled by a user's gaze for purposes such as controlling the movements of a wheelchair or general interaction with a computer [Adjouadi et al., 2004, Corno et al., 2002, Gajwani and Chhabria, 2010, Hornof and Cavender, 2005].

3. AUGMENTATION TECHNIQUES

In this section we describe two techniques that can enable users with a restricted range of physical head and/or eye rotation to view a 360-degree virtual environment while wearing an HMD. We first describe the setup and underlying coordinate systems before we describe the techniques in detail.

2.1 Setup and Coordinate Systems

Our setup consists of an off-the-shelf HMD (an HTC VIVE) with integrated eye tracking capabilities provided by a Pupil Labs add-on system. The HMD has a resolution of 2160×1200 pixels (1080×1200 per eye) and a refresh rate of 90 Hz, with a nominal field of view of around 110 degrees, and a weight of around 470 grams. Positional and rotational tracking is done by either 1 or 2 Lighthouse units delivered with the HTC VIVE, depending on whether the user is physically translating or not. The head tracking data is available in real-time to an application implemented in the Unity3D graphics engine using SteamVR 2018 plugin. The HTC VIVE also comes with hand-held controllers that can serve as an input device if needed. The eye tracker is integrated into the HTC VIVE using Pupil Labs' official add-on for this HMD. It has 120 Hz eye cameras and a gaze accuracy of about one degree and a gaze precision of about 0.08 degrees at a latency of 5.7 milliseconds (per the manufacturer). The HMD and the eye tracker are tethered to a graphics workstation with an Intel Xeon 2.4 GHz processor comprising 16 cores, 32 GB of main memory and two Nvidia GeForce GTX 980 Ti graphics cards. Additionally, the eye tracking data is sent from the manufacturer's Pupil Capture software to the Unity3D application via UDP using the Pupil Remote plugin and its Unity3D plugin [Pupil Labs, 2018]. Figure 1 shows an illustration of the considered setup and coordinate systems. It should be noted that while there are applications that make use of rotations about the *pitch* and *roll* axes, most use cases rely mainly on the *yaw* rotation, so we focus our descriptions on this axis. Pitch and roll rotations can be implemented using analogous approaches if desired. The techniques being proposed in this section can be applied to any virtual environment, and a user's range of head and eye motions can be collected both manually and automatically depending on the preference of the practitioner. The baseline range for head yaw rotations is 137.9 ± 13.6 degrees on either direction [LoPresti et al., 2003] and the baseline eye movement ranges for adduction and abduction are assumed to be 44.4 ± 6.9 and 44.8 ± 5.5 degrees respectively [Kim and Lim, 2017]. These values should be adjusted for each individual.

(a) (b)

Figure 1. *(a) Illustration of the head-centered coordinate system with yaw, pitch, and roll rotations in the considered VR setup. (b) Inside view of the HTC VIVE with the integrated Pupil Labs eye tracker consisting of infrared (IR) LEDs and binocular IR cameras.*

2.2 Continuous Rotation Technique

With this technique, the user can naturally look around the virtual world by rotating their head and/or eyes. However, since the range of physical head and eye rotations is limited, the technique has to provide a means to rotate the virtual view beyond the physical limitations. The *Continuous Rotation* technique does this by rotating the virtual view each rendering frame by an amount proportional to the angular difference between the user's current head/eye orientation and the center orientation, i.e., when the user's head/eyes are facing straight ahead. Hence, when the user rotates their head/eyes to look at an object toward the left, the view will slowly rotate the virtual world around the user's head until that object is located in front of them. To enable the user to explore their restricted field of view without triggering the continuous rotation, we can set a threshold angle that prevents the view to rotate if the center orientation is not exceeded by a specific amount (onset-threshold). An example with head movements using this technique is illustrated in Figure 2.

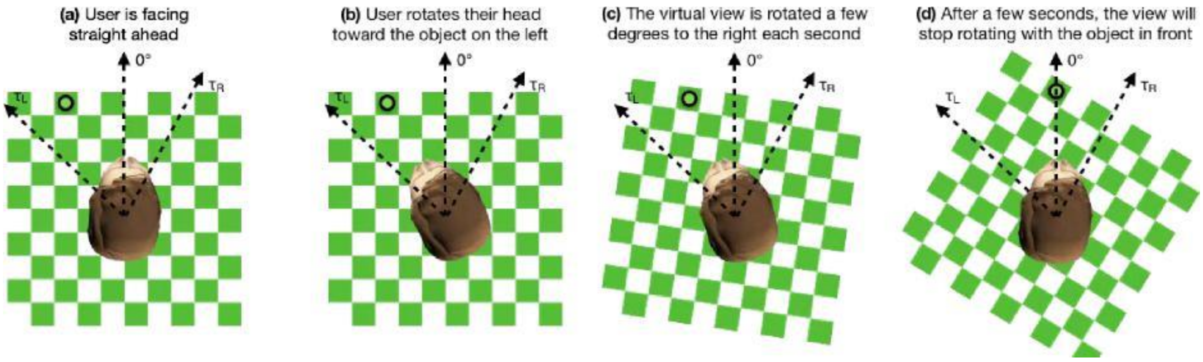

Figure 2. *Illustration of the head-tracked Continuous Rotation technique in an example sequence of head movements (a-d). The virtual environment is illustrated by the green checkerboard. Once the user's head rotates to the left or right, the virtual view is rotated slowly in that direction. If the user is facing toward a virtual object, the user will compensate for the subtle virtual rotation with physical head rotations until the object ends up directly in front of them and stops moving. The user can repeat this as often as desired. The eye-tracking based implementation uses the same approach except that the angles are taken from the eye tracker and not the head tracker.*

2.2.1 Head-Tracked Implementation.

The first background rotation technique was introduced by Razzaque et al. (2002), where they effectively rotated a user's viewpoint in a virtual world by a few degrees each frame of the rendering system. They argued that users may detect and respond to the continuously updated virtual camera orientation without recognizing the changes as external in origin, compensating for it by rotating their head if the magnitude is below the human susceptibility to such movements [Nilsson et al., 2018]. They applied the baseline rotation rate $r = 0.145$ degrees per second, but our impression, based on pilot testing and related work [Razzaque, 2005], is that even rotation rates of up to $r = 1$ degree per second are not considered as noticeably disorienting or distracting by users.

In order to account for usability variations, we can further multiply a dynamic scaling factor to this continuous baseline rotation, such that the maximum rotation rate is only applied when needed most, i.e., when the user's head is rotated far to the left or to the right. We therefore assume that the user's tracked head yaw orientation $\phi_{yaw} \in [\tau_L, \tau_R]$ is in a range defined by two thresholds $\tau_L, \tau_R \in [-180, 180]$ degrees around a predefined origin at $\phi_{yaw} = 0$ degrees, which corresponds to the user's head facing straight ahead. We assume that the two thresholds are predetermined for each individual to match their maximum comfortable head rotation range. Rotations beyond those thresholds should be avoided.

Using this approach, the velocity of the baseline rotation is scaled proportionally to the difference in yaw angle between the current head orientation and the orientation that corresponds to the user's initial forward orientation. The gain factors for the left and right side: $g_L = \sin(\phi_{yaw}/|\tau_L|\times 90)$ and $g_R = \sin(\phi_{yaw}/|\tau_R|\times 90)$ respectively, are calculated by computing the sine of the difference in yaw orientations up to the threshold, and applied in cases where $\phi_{yaw} < 0$ and $\phi_{yaw} > 0$ for the left and right, respectively. The resulting rotation rate is then computed each frame based on the updated scaling factor $g_L \in [-1, 1]$ and maximum rotation rate $r_{max} \in \mathbb{R}^+$ in degrees per second, where $r = r_{max}\, g_L$. As stated before, we found that a maximum rotation rate of $r_{max} = 1$ provides useful results in most cases, but this value can be tuned for each individual based on their susceptibility to such baseline rotations.

Thus, when the user rotates their head to the right, the virtual camera rotates to the left; and when the user rotates their head to the left, the virtual camera rotates to the right. The scaling factor causes the continuous rotation to be stronger when the user is facing farther toward either side, and zero when the user is facing straight forward. This is considered a *rate control* system [Wickens, 1992].

2.2.2 Eye-Tracked Implementation.

We can implement a similar continuous rotation technique using eye movements instead of head rotations. Therefore, we denote the tracked gaze yaw angle as $\phi_{yaw} \in [\tau_L, \tau_R]$ and define thresholds $\tau_L, \tau_R \in [-180, 180]$ degrees accordingly, just as in the head-tracked implementation in Section 2.2.1. The two thresholds are then predetermined for each individual to match their maximum comfortable eye rotation range, which should also be based on the range over which the eye tracker can accurately track the user's gaze, e.g., when the user is wearing thick corrective glasses.

The effect is that when the user is looking at an object that is located to their right, the object in their focus is then slowly rotated counterclockwise around the user (together with the rest of the virtual world) until it ends up remaining stationary straight in front of the user after a few seconds. If the user then looks at a different object to the left or right, the process repeats. Hence, the gaze data enables users to intuitively indicate the direction they want the virtual camera to rotate. Since the virtual world rotates only slowly during a continuous fixation of the eyes, it does not impair their normal gaze behavior when looking around in the virtual view in front of them. An onset-threshold or a voice-triggered disabling of the mechanism may be applied, respectively.

As with the head-tracked implementation in Section 2.2.1, for the eye-tracked implementation it is possible to set a maximum rotation rate. We consider a rotation rate of 1 degree per second a reasonable amount of rotation. However, we should point out that our goal is more to provide a smooth and comfortable interaction for users than to optimize the values for navigation in a virtual world or for performance in a specific task. Practitioners may adjust these values as desired.

2.3 Discrete Rotation Technique

The basic idea behind this technique is that users can naturally look around the virtual world in their individual comfortable range, e.g., by performing head rotations and/or looking around with their eyes alone. However, since this range is limited, a technique has to be introduced to rotate the view beyond that limit in the virtual world. With the *Discrete Rotation* technique, in order to rotate the view clockwise or counterclockwise from their current orientation, users can rotate their head or eyes in the desired direction until they approach their predefined individual threshold of comfortable head/eye rotations. Once movement approaching the threshold is detected by the head/eye tracker, the virtual view changes and is replaced by a new view that is rotated in the corresponding direction by a fixed amount. This amount is defined by the angular threshold, i.e., the view is rotated such that virtual content that was visible at the edge of the movement range before the discrete rotation is visible thereafter in the center of the user's view in front of them. To prevent an unwillingly triggered discrete rotation, e.g., induced by pain-triggered and/or unintentional movement, the rotation is only applied after an onset-threshold. This onset-threshold is implemented as a minimum range before the actual discrete rotation is applied. Figure 3 gives an example on how this technique can be used to rotate the view in VR with head movements.

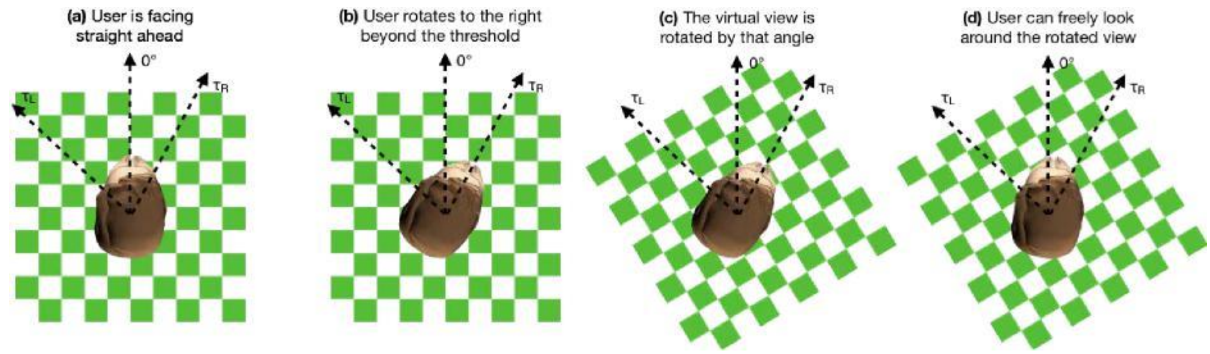

Figure 3. *Illustration of the head-tracked Discrete Rotation technique in an example sequence of head movements (a-d). The virtual environment is illustrated by the green checkerboard. Once the user's physical head orientation crosses the threshold τ_L or τ_R, the virtual view is rotated instantaneously in that direction by the angle corresponding to that threshold. The user can repeat this as often as desired to rotate the view. The eye-tracking based implementation uses the same approach except that the angles are taken from the eye tracker and not the head tracker.*

In contrast to the Continuous Rotation technique described in Section 2.2, this technique does not involve any continuous background rotations in the virtual world, instead introducing brief discrete rotations of larger magnitudes which can be implemented having immediate effects within the next frame or a lerp over a predefined amount of time. Such techniques are also known as *clutching* techniques [Argelaguet and Andujar, 2013] since they involve repeated shifts in the virtual environment by a fixed amount. By repeatedly moving
back and forth with the head or eyes, the user can move that view window in any direction and over any angular distance.

2.3.1 Head-Tracked Implementation

In this case, we assume that the user's head orientation is tracked by the HMD and that the user is capable of rotating their head, but only in a reduced range. Here we define the variables ϕ_{yaw} and τ_L, τ_R the same way as in Section 2.2.1.

When the user rotates their head, we look for orientations close to left and right thresholds denoted by $\phi_{yaw} < \tau_L + \varepsilon$ or $\phi_{yaw} > \tau_R - \varepsilon$, for some tolerance $\varepsilon \in \mathbb{R}^+$. Once such a head orientation is detected, the user's virtual view is rotated instantaneously by the angle ϕ_{yaw}. After that triggered rotation the user can rotate their head back toward the comfortable range between the thresholds and resume natural head rotations (looking around the virtual world) within that range, or they can further/again rotate the virtual view by rotating to the left/right threshold.

2.3.2 Eye-Tracked Implementation.

As an alternative to using head rotations, e.g., in case no physical head rotations are possible by the individual, it is possible to implement a similar clutching technique using eye movements. Here we define the variables $(0_{yaw}$ and T_L, T_R in the same way as in Section 2.2.2.

The user can naturally look around the view on the HMD while we look for left/right gaze rotations that approach the left and right thresholds denoted by $(0_{yaw} < T_L + C$ or $(0_{yaw} > T_R - C$, for a tolerance of $C c \mathbb{R}^+$. Once such a gaze angle is detected, the user's virtual view is rotated instantaneously by the angle $(0_{yaw}$. After that triggered rotation the user can look back toward the comfortable range between the thresholds, and resume natural looking around the virtual world, or they can further/again rotate the virtual view by again rotating their eyes to one side or the other, exceeding the thresholds.

An optional variation of this technique is to leverage *eye blinks* as an additional form of input. Instead of instantaneously rotating the view once the user crosses a threshold and looks towards the far angles of the display, the user can look in one direction and then perform a blink with their eyes to voluntarily trigger an instantaneous step in rotation. The advantage of this blink-induced technique is that users are less aware of the virtual world rotation, which can reduce discomfort associated with such brisk rotations. In the field of vision sciences, it is a well-researched concept that brief inter-stimulus intervals, such as when the eyes close and reopen during a blink, and associated perceptual masking processes can induce a phenomenon sometimes called *change blindness* [Simons and Levin, 1997], which denotes the perceptual illusion that persons are unable to notice even large changes in their visual field if it happens exactly at the same time [Bruder and Langbehn, 2017]. While using blinks is not mandatory in order to use this technique, it is our impression that such blink-induced rotations can greatly improve the visual comfort while using techniques such as this [Langbehn et al., 2018]. To prevent unintentional blinking-induced reorientation, we suggest blinking-patterns to be used for this approach.

Additionally, we propose an auto-adjustment for both techniques. Multiple attempts, e.g., numerous rapidly occurring eye movements toward one side of the visual field in order to reach a specific target indicates that the amount of discrete rotations is not sufficient for that particular user. Exceeding a threshold with this behavior would then trigger a dynamic adaptation of the rotation angle for each individual.

4. GENERAL DISCUSSION

In Section 3, we described two techniques with two realizations each that can be used to implement augmented virtual rotations, thus allowing users to look around a 360-degree virtual environment presented on an HMD. The head-tracked implementations can be applied for users who can rotate their head over a reasonable range depending on each individual, whereas the eye-tracked implementations can be applied for the same users or even such individuals who are incapable of rotating their head in the real world.

One advantage of the described techniques is that they do not require the user to manipulate any devices with their hands. As such, the techniques can be applied *hands-free* without the necessity for further instrumentation of the user. However, it should be noted that the described techniques only focused on *rotations* in a virtual world not *translations*. Not all applications in VR require the user to be able to change their position in the virtual world, such as when watching 360-degree VR movies. However, if desired, translations in the virtual world could be implemented through rotation-translation mode changes, e.g., via blinks or voice commands. We did not consider such translation techniques in the scope of this paper.

Another consideration when using these techniques is *simulator sickness*—possible sickness symptoms after longer-term use of a VR system [LaViola, 2000, Steinicke and Bruder, 2014]. The most common cause of simulator sickness in VR systems is a visual-vestibular conflict, which can arise when the visual feedback received from the virtual world does not match exactly the vestibular feedback received from the user's physical body senses. For instance, such conflicts arise when the virtual camera motion differs from the user's physical head movements [LaViola et al., 2001, Razzaque et al., 2002, Sargunam et al., 2017, Ragan et al., 2017]. Susceptibility to simulator sickness differs among individuals and sickness symptoms can be caused by different aspects of a VR system. The techniques presented in this paper can potentially induce more or less simulator sickness depending on the parameters and the person. We suggest that the thresholds and maximum rotations or rotation rates should be adjusted for each individual user to ensure that simulator sickness symptoms are kept within tolerance levels.

To systematically line out the field of applications for our techniques, we propose a rough classification of mobility impairments and best-practice reorientation techniques, these recommendations are based on past research on the techniques aimed at reorienting users while considering the induced simulator sickness reported for each technique; nonetheless other combinations can also be practiced.

As a practical guideline, if the user is able to perform natural eye movements (high) but has no or almost no mobility in head orientation (low) over a reasonable range depending on each individual, we recommend the use of the eye-tracked Discrete Rotation technique in conjunction with blinking as a triggering mechanism for the rotations. This approach has the benefit that it can be performed without requiring any physical head rotations. Moreover, this approach is likely to induce the lowest amount of simulator sickness, as there is no incongruent vestibular stimulation additional to the visual stimulation. Its main drawback is that the discrete rotations of the virtual world may induce moments of disorientation in a user, which should be taken into account. If the primary goal is to avoid disorientation, and the user is capable of a reasonable range of head rotations (head-mobility high, eye-mobility low), we recommend using the head-tracked Continuous Rotation technique. This technique has the benefit that it decouples the virtual camera rotations through the head orientation from the movement of the eyes. As such, the users will not be exposed to slight rotations of the virtual view whenever they explore the virtual world. In case there is a high mobility in both modalities, we propose a discrete reorientation triggered by eye blinking on top of the Continuous Rotation controlled by the head orientation.

The combination of both tracking-system can also be used for error prevention and correction of unintentional movement. A discrete orientation may only be applied if head/eye tracking thresholds are simultaneously exceeded, enabling the users to explore their limited FOV without unintentionally triggering the outlined mechanisms.

5. CONCLUSION

In this paper, we described two techniques based on continuous and discrete rotations of the virtual view in an HMD setup that can be applied to enable users to experience 360-degree rotations in a virtual world even when their physical head movements are severely restricted, e.g., when they are leaning against the headrest of a wheelchair. We presented two implementations for each of the two techniques, which are either based on head tracking data or eye tracking data. If the mobility allows both tracking modalities to be used, we proposed a combinational approach of both techniques that can greatly increase usability and reliability of our approaches. We discussed the advantages and disadvantages of the techniques and provided guidelines for practitioners in this field that may help them select one or multiple techniques in respect to the user's mobility. In future work, we plan to perform a user study in the subject field. We also hope to extend the work by further considering input from brain-computer interfaces as an additional condition.

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Traumatic brain injury with comorbid posttraumatic stress disorder affects performance on virtual reality-based balance tasks

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ABSTRACT

Robust functional assessments for service members who experience traumatic brain injury (TBI) and comorbid posttraumatic stress disorder (PTSD) remain challenging. At the National Intrepid Center of Excellence, the same preliminary virtual environments (VEs) acclimate all service members to the Computer Assisted Rehabilitation Environment (CAREN). The objective of this study was to determine whether time spent on the VEs (main outcome measure) differed between healthy service members and those with TBI or TBI and comorbid PTSD. Service members (N=121: Control=48; TBI-PTSD=42; TBI-No PTSD=31) completed the preliminary VEs, 1) Balance Balls: weight-shifting, and 2) Balance Cubes: step-shifting. Time spent on the Balance Balls and Balance Cubes were significantly correlated ($r = 0.561$; $p < 0.001$). For Balance Cubes, those with TBI-PTSD spent more time on the task than Controls ($p = 0.001$) and those with TBI-No PTSD ($p = 0.01$). Logistic regression showed that time spent on Balance Balls ($p = 0.019$) and Balance Cubes ($p = 0.002$) significantly predicted participant category (TBI-PTSD vs. Control), when controlling for age, study protocol, and Special Operations Command status.

1. INTRODUCTION

Traumatic brain injury (TBI) and posttraumatic stress disorder (PTSD) account for significant financial and personnel costs in the U.S. military (Tanielian and Jaycox, 2008). Between 2000 and 2017, 379,519 service members were diagnosed with TBI (DVBIC, 2018). Although reports vary, over one third of service members who experience concussion are also diagnosed with PTSD, and service members with a history of concussion and comorbid PTSD have a higher prevalence of postconcussive symptoms when compared to either condition alone (Hoge et al, 2008; Carlson et al, 2010; Brenner et al, 2010). Though each condition alone can have significantly negative impacts, the comorbidity of TBI and PTSD may be especially deleterious. For example, service members with a history of TBI more often report symptoms of dizziness, which can be magnified by posttraumatic stress (Akin and Murnane, 2011; Fife and Kalra, 2015). Additionally, service members with concussion and comorbid psychological health symptoms can present with impaired balance during higher level functional activities (Pape et al, 2015).

The overlapping symptoms of both conditions can present an enigma that falls outside the scope of conventional assessments (Taney et al, 2014). Without specific and sensitive assessment tools, the impact of TBI and PTSD comorbidity may remain poorly understood, leading to inadequate intervention. Current standards for differential diagnoses often involve interdisciplinary test batteries (Taney et al, 2014). At the National Intrepid Center of Excellence (NICoE), service members receive intensive, multidimensional evaluations from a comprehensive team of medical professionals over a four-week period. These evaluations include a combination of conventional and integrative health modalities ranging from music therapy to physical therapy, which can be enhanced by advanced technologies such as the Computer Assisted Rehabilitation Environment (CAREN) (Foote and Schwartz, 2012). Following evaluations by the NICoE vestibular team (which includes both audiologists and physical therapists) or by an orthopedic physical therapist, service members may be referred to the CAREN for additional evaluation/treatment if deemed clinically appropriate (e.g. displaying low functionality on conventional assessments). In such cases, technological advancements provide promising opportunities for more sensitive assessments and improved individualized intervention. Presently, the most frequent utilization of the CAREN at the NICoE is therapeutic intervention for multisensory integration, primarily for those with vestibular symptoms.

The CAREN is a relatively new technology (van der Eerden et al, 1999), with four systems employed within the U.S. Military Health System. The CAREN is equipped with several unique and innovative features while simultaneously providing a safe, controlled, immersive setting for care. Immersive experiences, like those in the CAREN, have been associated with improved outcomes through the translation of conventional clinical treatment to practical application (Lacour and Bernad-Demanze, 2015). As described in a comprehensive review by Collins et al. (2015), the system has been traditionally utilized for rehabilitation, as a tool for comparing injured and healthy controls, and to conduct studies with healthy participants. In the Military Health System, much of the CAREN literature has concentrated on therapeutic interventions for gait and balance deficits in service members with lower extremity amputations and those with TBI and vestibular dysfunction (Kruger, 2011; Beurskens et al, 2014; Sessoms et al, 2015). More recently, the value of CAREN-based assessment for tasks involving multisensory integration have also been reported in the literature (Brungart et al, 2015). The CAREN is viable as a rehabilitation tool, but also has promise as an assessment tool, setting forth a need to systematically examine its capabilities.

At the NICoE, a standard battery of preliminary virtual environments (YEs) has been utilized to acclimate service members to movement on the CAREN. All service members referred for clinical assessment or participating in research, complete the preliminary YEs during their initial minutes on the CAREN. The YEs are timed, requiring weight-shifting and strategy, which allow service members to adjust to the novel setting. Our retrospective analyses of these data for NICoE clinical patients found that service members with TBI who endorsed more severe symptoms of PTSD spent more time on these tasks than those who did not (Onakomaiya et al, 2017). However, the study was conducted in a clinical sample from the NICoE patient population, thus all the service members had TBI or both TBI and comorbid PTSD. There were no uninjured service members to recruit as a control group.

Therefore, the primary objective of this study is to determine whether service members with TBI and comorbid PTSD spent more time on the preliminary YE tasks on average than healthy uninjured service members in a prospective study. We also sought to compare performance of service members with TBI, with and without comorbid PTSD, to see if our findings from the retrospective sample would be replicated in a prospective cohort. We hypothesized that in a prospective study, service members with a history TBI and comorbid PTSD would spend the most time on the YE tasks compared to service members with a history of TBI without comorbid PTSD and healthy uninjured controls.

2. METHODS

The data used for this cross-sectional study were collected as part of two separate prospective research studies conducted at the NICoE from 2013-2017 (Table 1). All study procedures were reviewed and approved by the Department of Research Programs' institutional review board (IRB) at Walter Reed National Military Medical Center.

2.1 Participants

A total of 121 service members (Control=48; TBI-PTSD=42; TBI-No PTSD = 31) completed the preliminary YEs and provided written informed consent to participate in research at NICoE involving the CAREN. Healthy, non-blast exposed service members with no history of TBI or psychological trauma were recruited into the Control group. Service members in the NICoE four-week program with a history of mild or moderate TBI and comorbid psychological health symptoms were recruited into the TBI-No PTSD and TBI-PTSD groups. Any service members referred to the CAREN for therapeutic intervention prior to recruitment into the research study were excluded, to mitigate any potential differences in baseline exposure to the CAREN system.

2.2 Self-Report Questionnaires

TBI status was confirmed via the Defense and Veterans Brain Injury Center (DVBIC) TBI Screening Tool, while probable PTSD was determined by the PTSD checklist – Military Version (PCL-M) questionnaire. Additionally, Question 3 of the DVBIC TBI Screening Tool was also used to account for self-reported headaches, dizziness, and balance problems in the TBI-No PTSD and TBI-PTSD groups.

2.2.1 DVBIC TBI Screening Tool

A validated three-question, self-report instrument designed to evaluate and identify service members who may need further evaluation for TBI (Schwab et al, 2006). Question 3 of the tool asks about current symptoms and we used this to determine self-reported headache, dizziness, and balance problems. The question asks "Are you currently experiencing any of the following problems that you think might be related to a possible head injury or concussion? (Check all that apply): A. Headaches, B. Dizziness, C. Memory problems, D. Balance problems, E. Ringing in the ears, F. Irritability, G. Sleep problems, H. Other specify."

2.2.2 PTSD Checklist – Military Version

A validated self-reported 17-item screen for PTSD to determine the degree to which participants were bothered by symptoms in the past month (Keen et al, 2008). Total score ≥ 50 is generally considered to be indicative of probable PTSD.

2.3 Preliminary Virtual Environments

The preliminary VEs were performed on the CAREN (Motekforce Link, Amsterdam, Netherlands). The CAREN includes a motion platform and operates in combination with a motion capture system (Vicon Motion Systems Ltd., Oxford, United Kingdom) which tracks the movement of reflective markers placed on the service member, allowing for interaction with and/or control of each VE. The system is surrounded by a large, 180-degree curved screen on which VEs are projected (Figure 1). To ensure safety during utilization, service members received a safety brief and were tethered to the safety stand by a full body harness. Each VE was performed once.

2.3.1 Balance Balls

This VE provides an acclimation to weight-shifting on a static platform; main outcome measure was time in seconds taken to complete the task (Figure 2A). For this task, two reflective markers were placed immediately above the pelvis, on the back of the safety harness, and synced to a yellow ball in the center of the screen. Red balls appeared sequentially at random positions on the screen, requiring service members to weight-shift (feet planted) to move the yellow ball to hit each target, returning to center before the next red ball appeared.

2.3.2 Balance Cubes

This VE provides an acclimation to step-shifting on a static platform; main outcome measure was time in seconds taken to complete the task (Figure 3A). For this task, service members were synced to a white diamond with the same marker placement as described above for the Balance Balls VE. Different colored cubes appeared at random positions on the screen, requiring service members to step-shift on the platform to move the diamond to hit each target. Service members were required to move from one target cube to the next, as the cubes appeared sequentially.

2.4 Data Integrity

Data were obtained by manual extraction from self-report questionnaires and CAREN data collection forms. Data were compiled into an encrypted, password-protected database where study participants were designated by unique study identification numbers. Prior to analysis, two blinded, independent reviewers reviewed the dataset for integrity and quality assurance.

2.5 Data Analysis

Statistical analyses were conducted in SPSS 19. The main outcome variables were time spent (in seconds) on the Balance Balls and Balance Cubes VEs. Pearson's correlation determined significant correlations across the VE tasks and age. Chi Square tests determined significant group differences in the number of participants per group for demographic variables (gender, Special Operations Command (SOCOM) status, and headache, dizziness and balance problems on the DVBIC TBI Screening Tool) and study protocol, means are reported ± standard deviation (Table 2). A one way ANOVA with Bonferroni correction determined between group differences (Control vs. TBI-No PTSD vs. TBI-PTSD) in demographics and time spent on the VE tasks. Then a binary logistic regression assessed whether time spent on the VE tasks predicted participant category when comparing TBI-PTSD vs. Control and TBI-PTSD vs. TBI-No PTSD, adjusting for the effects of relevant demographic variables. A receiver operating characteristic (ROC) area under the curve (AUC) analysis determined VE task performance sensitivity and specificity.

3. RESULTS

As shown in Table 2, overall, service members mean age was 34.5 (± 6.8 years) with a range from 20 to 47 years. The majority of participants were male (95.8%) and 31.4% were service members assigned to the SOCOM. There was a significant difference in age between service members in the Control group and those in both the TBI-PTSD ($p = 0.003$) and the TBI-No PTSD ($p < 0.001$) groups, who tended to be older than service members in the Control group (Table 2). There was also a significant difference in the representation of service members with SOCOM status because none of the service members in the Control group had SOCOM status while 16 and 22 service members had SOCOM status in the TBI-PTSD and TBI-No PTSD groups respectively (Table 2). We adjusted for these variables in later regression analyses. There were also significant differences in the number of service members in the TBI-No PTSD and TBI-PTSD groups with self-reported dizziness ($\chi 2 = 4.360$; $p = 0.037$) and balance problems ($\chi 2 = 5.306$; $p = 0.021$) but not headaches on the DVBIC TBI screening tool (Table 2). We were unable to adjust for these variables in later regression analyses because there were no screening data from the control group.

Time spent on the Balance Balls VE was significantly correlated with time spent on the Balance Cubes VE ($r = 0.561$; $p < 0.001$), but neither was correlated with age. For the Balance Balls VE, service members with TBI-PTSD spent the most time (62.48 ± 27.07 seconds), followed by service members with TBI-No PTSD (58.19 ± 14.45 seconds), and Controls (54.40 ± 13.19 seconds), but this was not statistically significant ($F_{2,117} = 1.908$, $p = 0.153$; Figure 2B). For the Balance Cubes VE, service members in each of the three groups spent less time on this VE than the Balance Balls VE. Here, the mean differences in time spent followed the same order but attained statistical significance ($F_{2,117} = 7.916$, $p = 0.001$; Figure 3B) such that service members in the TBI-PTSD group spent the most time (57.29 ± 12.64 seconds) followed by service members with TBI-No PTSD (50.39 ± 8.81 seconds), then service members in the Control group (49.54 ± 7.09 seconds). Post hoc pairwise comparisons with Bonferroni adjustment showed that service members with TBI-PTSD spent significantly more time than service members in the Control ($p = 0.001$) and TBI-No PTSD groups ($p = 0.01$). The difference in time spent was not significant between service members in the TBI-No PTSD and Control groups ($p = 0.925$).

A binary logistic regression showed that time spent on the Balance Balls VE significantly predicted participant category between the TBI-PTSD and control groups [$p = 0.019$; OR 1.058 (95% CI 1.009, 1.108)], when adjusting for age, study protocol, and SOCOM status, such that a one second increase in time spent on the Balance Balls VE was associated with a 5.8% increased odds of being in the TBI-PTSD group. The Balance Cubes VE significantly predicted participant category between the TBI-PTSD and control groups [$p = 0.002$; OR 1.163 (95% CI 1.058, 1.279)] when adjusting for age, study protocol, and SOCOM status such that a one second increase in time spent on the Balance Cubes VE task was associated with a 16.3% increased odds of being in the TBI-PTSD group. Additionally, the ROC analysis area under the curve (AUC) for both the Balance Balls (AUC = 0.843; $p < 0.001$; Figure 4A) and the Balance Cubes VEs (AUC = 0.879; $p < 0.001$; Figure 4B) were modest but statistically significant.

Similar to our retrospective findings (Onakomaiya et al, 2017), logistic regression showed that Balance Cubes VE significantly predicted participant category between the TBI-PTSD and TBI-No PTSD groups [$p = 0.020$; OR 0.930 (95% CI 0.874, 0.989)], such that a one second increase in time spent on the Balance Cubes VE was associated with a 7.0% decreased odds of being in the TBI-No PTSD group. When adjusting for headaches, dizziness, and balance problems, the odds were lower but still statistically significant [$p = 0.045$; OR 0.934 (95% CI 0.873, 0.999)]; a one second increase in time spent on the Balance Cubes VE was associated with a 6.6% decreased odds of being in the TBI-No PTSD group. However, when also adjusting for age, study protocol, and SOCOM status, this observation was no longer statistically significant [$p = 0.129$; OR 0.940 (95% CI 0.887, 1.018)]. The Balance Balls VE did not significantly predict participant category between the TBI-PTSD and TBI-No PTSD groups, whether or not we adjusted for headaches, dizziness, balance problems, age, study protocol, and SOCOM status.

4. DISCUSSION

Across two prospective studies of performance on two CAREN VE tasks, service members with a history of TBI and comorbid PTSD spent significantly more time on a step-shifting task (Balance Cubes VE) than service members with TBI without PTSD, and uninjured controls. This suggests that in service members with a history of TBI, PTSD may further affect performance on physical tasks in VEs. These findings support our recent retrospective study of clinical data from service members with a history of TBI comparing those with and without PTSD (Onakomaiya et al, 2017). Previous studies have highlighted the potential implications of the pathophysiological impact of TBI and comorbid psychological health symptoms on balance and vestibular impairment (Fife and Kalra, 2015; Dolan et al, 2012; Franke et al, 2012). In particular, some suggest that comorbid PTSD may worsen the expression of postconcussive symptoms (Wares et al, 2015), which raises the possibility that addressing the impact of PTSD during treatment may be effective in ameliorating impairment after TBI (Bryant, 2011). However, since understanding the pathophysiological mechanisms of this interaction have not been established and there is evidence to suggest that PTSD in the context of a TBI may be different from either condition alone, interventions may need to be adjusted for service members with TBI and comorbid PTSD (Howlett and Stein, 2016).

The causes of the differences between service members with TBI and comorbid PTSD, versus service members with TBI without PTSD, are still unclear. We can hypothesize about what may contribute to the differences observed in performance on the static weight-shifting versus the dynamic step-shifting tasks in our study. One possibility is that it could be the result of potential differences in the central and peripheral neural pathways required to complete the VEs. The addition of movement, across the platform surface, would require a multisensory approach for maintaining balance and therefore the incorporation of vestibular, visual, and somatosensory information for central processing (Dieterich and Brandt, 2015). In either case, poor somatosensory or vestibular integration may lead to increased compensatory strategies.

PTSD may further suppress the central vestibular system and the multisensory integration, which could explain why service members with comorbid TBI-PTSD spent the most time on the Balance Cubes VE (Figure 3B). However, in one study of nine football players after concussion, Powers et al. (2014) reported that while medial-lateral motion was mostly recovered by the time players returned to play, anterior-posterior motion was still impaired (Powers et al, 2014). Therefore, while the confounding comorbidity of the PTSD may affect performance time, other unmeasured factors that may be important for performance of the VE tasks, such as attention, cognitive ability, orthopedic restrictions and medications, may also contribute to the differences we observe. Moreover, PTSD is associated with the impairment of several of these factors, including attention, executive function, processing speed, and contextual information processing (Shalev et al. 2017). Future work will investigate whether PTSD symptoms mediate the effects observed using more detailed and targeted standardized clinical assessments of balance and vestibular integration.

Dizziness and balance complaints are relatively common in people with a history of TBI (Fife and Kalra, 2015). There are several potential mechanisms that may be involved, including the physical trauma that led to the TBI, as well as psychological comorbidities including PTSD, depression, and anxiety (Herdman et al, 2012; Fife and Kalra, 2015). In our study, we found that there was a higher number of service members with self-reported balance and dizziness complaints in the TBI-PTSD group than the TBI-No PTSD group (Table 2), suggesting that we cannot rule out the possibility that PTSD symptoms may have an effect on somatosensory integration in this sample. Several studies have reported associations between psychiatric disorders (particularly anxiety) and dizziness and/or balance complaints in civilian samples (Yardley et al, 1998; Yardley, 2000; Balaban and Thayer, 2001; Jacob et al, 2009). Other studies have reported associations between PTSD and somatic symptoms such as dizziness, in patients without a history of TBI, such that patients with PTSD showed improvement in physical symptoms after conventional interventions such as Cognitive Behavioral Therapy, serotonergic antidepressants, and/or vestibular rehabilitation (Staab, 2006, 2011; Staab et al, 2012; Edelman et al, 2012).

As discussed in our previous study (Onakomaiya et al, 2017), hypervigilance is a central dimension of PTSD and may partially explain or confound our observation of slower times in service members with TBI-PTSD because of exposure to an unfamiliar environment. Since some of the service members in our study had both TBI and probable PTSD, the source of the central vestibular disturbances and difficulties with sensory integration may be due to TBI, PTSD, a combination of both or an unmeasured factor. However, understanding if and how the severity of PTSD symptoms influences the integration of vestibular information into the central nervous system and whether that affects functional performance remains to be established. This may be relevant to the implementation of therapeutic interventions. For example, service members with TBI-PTSD may require additional time to complete certain tasks during physical or cognitive rehabilitation (Onakomaiya et al, 2017).

Finally, our results indicate that CAREN YEs can be useful in distinguishing service members with comorbid TBI-PTSD from service members without PTSD and uninjured controls. We found that performance on the CAREN preliminary YEs significantly predicted participant category between TBI-PTSD and control groups, supporting the value of using these tasks to augment clinical assessment for service members with TBI and comorbid PTSD. Furthermore, since service members with TBI and comorbid PTSD spend more time on the YE tasks than those with TBI-No PTSD, clinicians selecting YEs for further vestibular rehabilitation need to consider that the same performance time should not be expected between these subpopulations. Of note, when adjusting for several demographic variables the odds of predicting between TBI-No PTSD and TBI-PTSD was no longer statistically significant suggesting the need for further investigation. Regardless, given the continued need for objective, functional assessments for individuals with TBI, technologies that harness YEs to approximate integrative activities are increasingly useful, particularly for service members with comorbidities after traumatic experiences.

5. LIMITATIONS

This study has several potential limitations. First, we were not able to study the performance of service members with PTSD alone and thus cannot determine if and how differently they would perform on these YEs. Future work should assess CAREN performance times in service members with PTSD to begin to disaggregate the effects of TBI and PTSD symptoms in service members with comorbidity. Second, all data were collected at a single, tertiary care center, so there may be elements of referral or selection bias, particularly in the participants with a history of TBI and with balance or vestibular deficits. We attempted to mitigate this limitation by carefully controlling for known group differences in our analyses. Third, because the protocols for the two studies were designed with different foci, there were some disparities in which standardized clinical measures and self-report questionnaires were collected between the two studies. Thus, we were limited to analyzing those that were collected in both studies with high fidelity. Fourth, there were significant differences in demographics between the three groups such that service members in both TBI groups were older than service members in the Control group on average, and all five female participants were in the Control group. Furthermore, the representation of service members with SOCOM status was also significantly different between participants in the two TBI groups, and no service member in the uninjured Controls group had SOCOM status. The TBI-No PTSD group in particular, had the highest representation of service members with SOCOM status (71%) and this group performed similarly to the uninjured Control group in both YE tasks. If and how specialized training may have influenced this observation will be the subject of future work. To account for any potential effects of age, study protocol, and specialized training on our statistical analyses, we adjusted for these variables in the latter regression analyses. Fifth, because these data were compiled from other studies, potential confounders of dynamic balance including medications, orthopedic concerns, substance use disorders, and sleep problems, could not be accounted for directly in our analyses. Also, we could only account for the headache, dizziness and balance problems reported on the DYBIC screening questionnaire for the TBI-No PTSD vs. TBI-PTSD regression analyses because these data were not available for the control group. Finally, the use of self-report measures introduces the possibility of recall bias. We attempted to mitigate this by using validated questionnaires in the confirmation of TBI status and probable PTSD.

6. CONCLUSIONS

Similar to our findings in a retrospective study of clinical data (Onakomaiya et al, 2017), combined data from two prospective studies found that service members' performance on the CAREN preliminary YE tasks differed by participant category. We found that service members with TBI and comorbid PTSD spent more time on the dynamic step-shifting task than healthy uninjured service members, when controlling for age, study protocol, and SOCOM status. This provides additional evidence to support the value of using the CAREN preliminary YEs in the assessment and treatment of service members with TBI and comorbid PTSD. Despite the limited availability of CAREN systems, taking an evidence-based approach to determine which YEs are most effective for this patient population is important, especially when considering how the system might be pared down to more accessible virtual reality systems as these technologies become more portable, affordable, and readily available for clinical utilization. Future work will also determine if there are clinically meaningful ranges or thresholds on these tasks either discretely or as a composite that could assist in differential diagnoses.

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TABLES

Table 1. *Study Protocol by Participant Category*

	Healthy Control (n = 48)	TBI-PTSD (n = 42)	TBI-No PTSD (n = 31)	Total (n = 121)
# of Participants from Study 1	31	17	31	79
# of Participants from Study 2	17	25	0	42
$\chi 2 = 27.902$; $p < 0.001$				

Table 2. *Demographics by Participant Category*

	Healthy Control (n = 48)	TBI-PTSD (n = 42)	TBI-No PTSD (n = 31)	Total (n = 121)
Age in years (Mean ± SD)	31.1 ± 6.5	35.4 ± 6.9	38.7 ± 3.6	34.5 ± 6.8
PCL-M Score (Mean ± SD)	-	63.3 ± 9.2	36.0 ± 8.0	-
# DVBIC Headache (%)	-	34 (81%)	25 (81%)	-
# DVBIC Dizziness (%)	-	21 (50%)	8 (26%)	-
# DVBIC Balance (%)	-	19 (45%)	6 (20%)	-
# Special Forces (%)	0	16 (38%)	22 (71%)	38 (31%)
# Male (%)	43 (90%)	42 (100%)	31 (100%)	116 (96%)

FIGURES

Figure 1. *The CAREN Laboratory at the NICoE. Photo courtesy of NICoE.*

Balance Balls VE

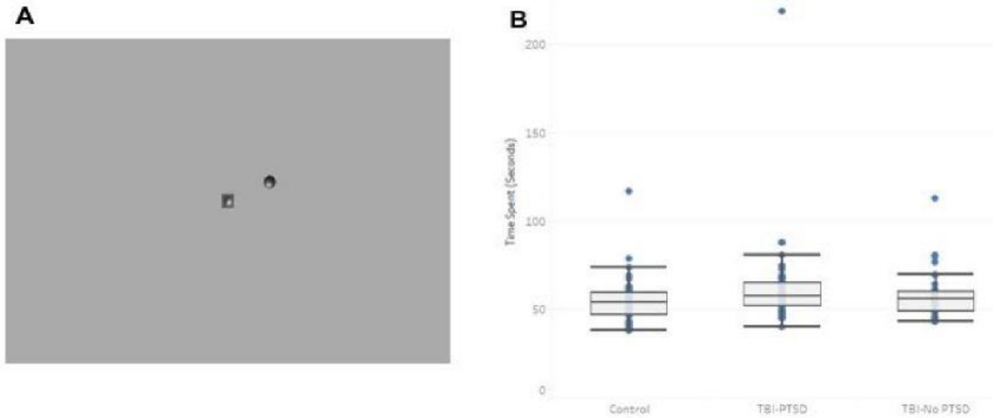

Figure 2. *A) Screenshot of the Balance Balls VE. B) Boxplots showing the distribution of time spent for each of the three participant categories (Control, TBI-PTSD, and TBI-No PTSD) on the Balance Balls VE task. The mean differences were not statistically significant ($F_{2,117}$ = 1.908, p = 0.153).*

Balance Cubes VE

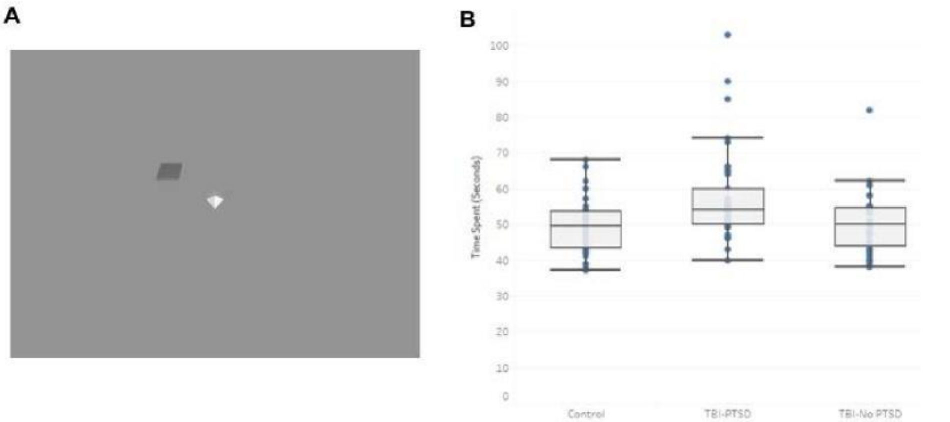

Figure 3. *A) Screenshot of the Balance Cubes VE. B) Boxplots showing the distribution of time spent for each of the three participant categories (Control, TBI-PTSD, and TBI-No PTSD) on the Balance Cubes VE task. The mean differences were statistically significant ($F_{2,117}$ = 7.916, p = 0.001) such that service members in the TBI-PTSD group spent significantly more time on the VE than service members in the Control (p = 0.001) and TBI-No PTSD (p =0.01) groups.*

Balance Balls VE **Balance Cubes VE**

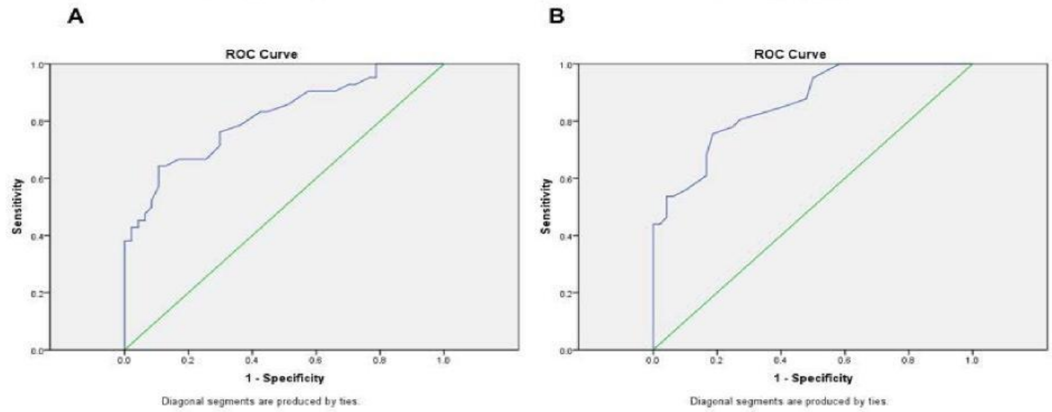

Figure 4. *Receiver Operating Characteristic (ROC) Curves showing the area under the curve (AUC) for Control vs. TBI-PTSD in the A) Balance Balls VE (AUC = 0.843; p < 0.001), and B) the Balance Cubes VE (AUC = 0.879; p < 0.001). These values were modest but statistically significant.*

Exploring materials and object properties in an interactive tangible system for upper limb rehabilitation

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ABSTRACT

Here we present an exploratory study to assess the feasibility, motivation and usability of a novel system that uses tangible objects of different shapes and materials to interact with virtual tasks designed for upper limb rehabilitation after stroke. 5 different tasks were developed and tested with 5 types of tangible interaction (3 grasp and 2 strength modalities). Data on 5 stroke survivors show that the proposed interactive paradigm is feasible and engaging, and that its usability is modulated by the user's functional abilities. Hence, tasks dynamics and features need to be improved to increase usability for patients with more functional and cognitive difficulties.

1. INTRODUCTION

Stroke remains one of the biggest health problems worldwide, being the third most common cause of disability (Feigin et al., 2014). After a stroke, approximately 70-80% of survivors will experience some level of upper limb impairment (Langhorne, Coupar, & Pollock, 2009; Party, 2012), with 50% remaining with permanent deficits after one year of rehabilitation. These deficits impact functionality and independence in Activities of Daily Living (ADL) (Haghgoo, Pazuki, Hosseini, & Rassafiani, 2013; Pollock et al., 2014), and often lead to social isolation (Kruithof et al., 2015; Northcott, Moss, Harrison, & Hilari, 2016; Volz, Möbus, Letsch, & Werheid, 2016). In addition, stroke survivors commonly present depressive symptomology, which can strongly hamper the recovery process (Ahn, Lee, Jeong, Kim, & Park, 2015; Flaster, Sharma, & Rao, 2013). As such, it is a research priority to find new rehabilitation strategies to foster functional improvement and well-being after stroke.

Technology-based rehabilitation paradigms, such as virtual rehabilitation, have been widely studied for motor and cognitive recovery after stroke (Laver, George, Thomas, Deutsch, & Crotty, 2015; Lohse, Hilderman, Cheung, Tatla, & Van der Loos, 2014). These systems allow delivering structured rehabilitation programs through graded adaptations, and provide challenging and meaningful activities that have the potential to promote increased motivation and treatment compliance (Laver et al., 2015; Viñas-Diz & Sobrido-Prieto, 2016). However, it has been observed that the form of interaction can have an impact on outcomes and acceptance of these novel rehabilitation tools (Mousavi Hondori et al., 2016). For instance, with older populations, evidence suggests that interaction is easier the more direct it is. That is, using the body to interact through touch and getting immediate feedback right where the interaction occurred. Direct interaction through object manipulation better resembles ADL in terms of hand-eye coordination and has been shown to correlate with clinical scores (Khademi et al., 2014).

Research on the use and impact of tangibles in interactive systems for stroke rehabilitation is still scarce (Magnusson et al., 2017). Hilton *et al.*, conducted one of the first studies that explored the use of a tangible interface during a virtual reality task for upper limb rehabilitation (Hilton, Cobb, Pridmore, & Gladman, 2002). A tangible interface was chosen because it allowed having a naturalistic and realistic scenario to simulate instrumental ADL in Virtual Reality (VR). Nevertheless, several technical limitations concerning the use of objects during the task were encountered, such as feedback issues and undesired activation of sensors. During the last few years, this type of technology has however matured immensely, and the onset of new systems that support the use of multi-touch and tangible objects has facilitated their integration in rehabilitation (Jacobs, Timmermans, Michielsen, Vander Plaetse, & Markopoulos, 2013; Kelliher, Choi, Huang, Rikakis, & Kitani, 2017; Leitner, Tomitsch, Költringer, Kappel, & Grechenig, 2007). Recent studies indicate the feasibility of using this technology for stroke rehabilitation in a clinical setting or at home (Kelliher et al., 2017), with good levels of acceptance being reported by healthcare providers (Leitner et al., 2007; Wang, Koh, Boucharenc, Xu, & Yen, 2017). Particularly promising is the increased ecological validity of task execution by manipulating physical objects in these systems, which has potential to improve learned competences and transfer to real world execution of ADL (Jacobs et al., 2013; Kelliher et al., 2017). Similar advantages can be seen in haptic interfaces. In a study with chronic stroke, the use of haptics combined with VR led to improved outcomes 12 weeks after intervention in comparison to other modalities such as vision-based tracking or using a passive exoskeleton (Cameirão, Badia, Duarte, Frisoli, & Verschure, 2012). Particularly

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interesting are haptic interfaces that allow simulating grasping of objects. For example, the *Wolverine* system that is able to render 75% of a list of objects of daily life (Choi, Hawkes, Christensen, Ploch, & Follmer, 2016). Such devices are promising for an ecologically valid training of ADLs in VR.

While these preliminary studies show positive results on the use of interaction with tangible objects and/or touch surfaces, some issues have not yet been fully explored. Specifically, it is important to understand how tangible interactive systems, their objects and material properties can be designed to provide comprehensive rehabilitation tasks that are flexible and adaptable to users with different clinical profiles, and that can promote motivation for long-term use. For this purpose, we developed a prototype interactive surface that uses camera-based tracking to identify objects of different properties. Through 5 different tasks, the user can manipulate objects of different materials (for example, therapy putty and wooden objects), shapes, sizes, and resistances to accomplish specific goals. The different tasks were designed to train different motor competences of the hand, namely strength, dexterity, coordination and grasping. The objects tested in this study were specifically selected to address only three different types of grasp (power grasp, lateral grasp and tripod grasp) and strength training. With this prototype we want to achieve three research goals. The first goal is to analyze what types of objects and task mechanics are more feasible to be used for rehabilitation by stroke survivors with different levels of impairment. The second and third goals are to assess the motivation and usability of the proposed approach, respectively.

Here we present a detailed analysis of the performance and self-reported feedback of 5 stroke survivors that performed the 5 interactive tasks with different types of tangible objects. Our results show the feasibility of the proposed system for grasp and strength training, exploiting different material properties in an interactive tangible surface.

2. METHODS

2.1 Experimental Setup

The setup consists of a PC (OS: Windows 8.1, CPU: i7-4790 at 3.60GHz, RAM: 8Gb, Graphics: GeForce GTX 1060 6GB), a PlayStation Eye camera (Sony Computer Entertainment Inc., Tokyo, Japan), a 32” TV placed horizontally, and a set of tangible objects (Figure 1). A chair with adjustable height and a bench for feet rest were used to guarantee a correct posture during the session.

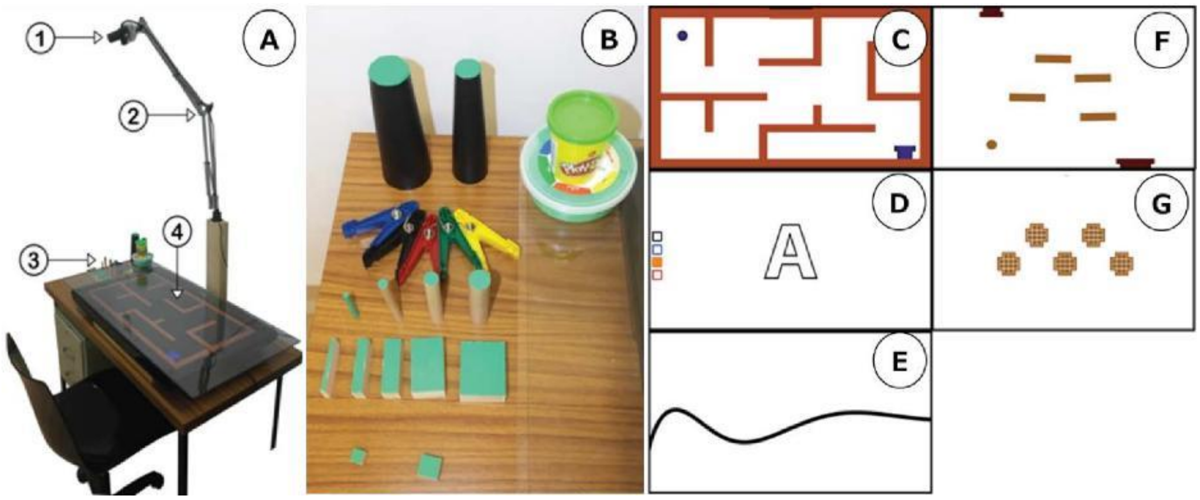

Figure 1. (A) Experimental setup (1-Camera; 2-Supporting arm 3-Set of tangible objects; 4-TV Screen), (B) Tangible objects used to interact with the tasks, and screenshots of (C) *Maze*, (D) *Paint*, (E) *Follow the line*, (F) *Slide*, and (G) *Fill the figure*.

For object tracking, we created a custom software using the OpenCV Source Computer Vision Library, able to detect an arbitrary number of objects from a previously defined colour list, providing their colour (Hue, Saturation and Value values), centre position relative to the camera, area, perimeter and more importantly, a list of coordinates defining the perimeter of each object. All this information is transmitted to the game, implemented in Unity3D, through a UDP socket connection. The tracking software requires a calibration process to account for the light conditions since colour properties can change from the camera’s point of view. The software takes the values from the calibration and then applies to each frame thresholding operations to extract Binary Large Objects (BLObs), which refers to a group of connected pixels in a binary image. The term "Large" indicates that only objects of a certain size are of interest since "Small" binary objects are usually noise. The camera would not always be perpendicular to the display, so we created a perspective calibration procedure that corrects the image perspective and crops it by selecting the four corners of the display.

Objects with different characteristics were used for the interaction (Table 1). These were chosen based on materials used for upper limb rehabilitation in standard occupational therapy (Leung, Ng, & Fong, 2009). Objects of different sizes and resistances were used depending on the skill level of each participant. Objects were chosen to allow the three most frequently used types of grasp (power or global grasp, lateral grasp and tripod grasp) (Figure 2) (Feix, Romero, Schmiedmayer, Dollar, & Kragic, 2016) and hand/finger strength training. Selection of the object to be used in each competence (grasps and strength) training for each task was made by a therapist based on the initial assessment and the ability of the user to manipulate the object. It was ensured that the manipulation of objects was comfortable but also challenging, as it is intended to simulate a rehabilitation task. We opted to use only one object per competence and task because of the large number of possible objects and to avoid exposing the user to very easy or very difficult performances, thus preventing boredom or frustration, respectively.

Table 1. *Objects' characteristics.*

Cubes	**Cylinders**	**Parallelepipeds**	**Cones**	**Pinch Pins**	**Putty/Plasticine**
Edge (mm)	Diameter(mm)	Length (mm)	Diameter	Resistance (Kg)	Resistance
	22	45	Small	Yellow – 0,45	Plasticine (Play-doh®)
15	15	30	Bottom - 50	Red – 0,9	Extra-soft putty
	10	15	Top - 30	Green – 1,8	Soft putty
	6	10	Large	Blue – 2,7	Medium putty
1		5	Bottom- 70	Black – 3,6	Firm putty
			Top - 50		Extra-firm putty

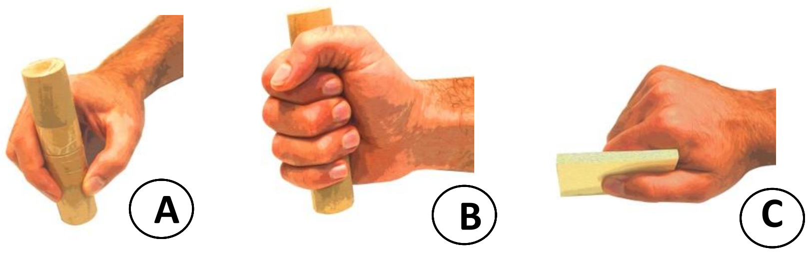

Figure 2. (A) Tripod grasp, (B) Power grasp and (C) Lateral grasp.

2.2 Tasks

5 tasks (*Maze*, *Paint*, *Follow the line*, *Slide*, *Fill the Figure*) were developed to exploit different object properties and to train specific competences of the upper extremity (Figure 1). All tasks were developed as independent applications using Unity and receiving information from the tracking software through a UDP connection. The tasks are the following:

- *Maze* - the participant has to push a ball through a maze and introduce it into an exit tube at the other end of the maze;
- *Paint* – the participant chooses a colour (blue, yellow or red) and the objective is to paint the letter "C" in a free style. The participant can erase and rewrite the letter until he/she is satisfied with the result;
- *Follow the line* – the participant has to follow a line with an object, trying to be as precise as possible. When performing the task, a trace is drawn with the object. To avoid occlusion of the feedback with the hand, when the left hand is used, the line must be followed from right to left, and vice-versa in order to avoid the object to occlude the feedback of the line being drawn;
- *Slide* – the participant has to create a path with objects for a ball that falls and bounces on them to guide it to the exit tube at the bottom of the scenario;
- *Fill the figure* – the participant has to fill a given shape using objects.

2.3 Sample, Recruitment, and Clinical

Participants of the study were a convenience sample recruited from two public hospitals in Funchal, Portugal. The inclusion criteria were to have suffered a stroke and having upper limb impairment. Exclusion criteria included: null or full functionality of the upper extremity as measured with the Action Research Arm Test (ARAT) (Carroll, 1965; Lyle, 1981); severe cognitive deficit that compromises the understanding of the task, with a score lower than 17 in the Token Test (De Renzi & Vignolo, 1962); hemispatial neglect, assessed through a cancellation test; and no literacy. The study followed established guidelines concerning research with human participants, and all participants provided informed consent.

Fifteen stroke survivors were considered potential participants for this study and 5 met inclusion criteria (Table 2). Our sample is composed of four males and one female, with a mean age of 67.4±13.7 years (range: 51-80), and 27.8±31.3 weeks post stroke. All had 4 years of schooling, were able to read and write, and none had previous experience with computers. Participants underwent motor and cognitive assessments through standard clinical scales in order to identify their level of skill. The motor assessment was done through the Fugl-Meyer Assessment (FMA) – Upper Extremity (Fugl-Meyer, Jääskö, Leyman, Olsson, & Steglind, 1975) and the ARAT for motor functioning; the Box and Blocks Test (BBT) (Cromwell, 1976; Mathiowetz, Volland, Kashman, & Weber, 1985) for gross manual dexterity; a dynamometer to measure power grasp strength; and the Modified Ashworth Scale (MAS) (Sloan, Sinclair, Thompson, Taylor, & Pentland, 1992) for spasticity. The cognitive characterization was done through the Montréal Cognitive Assessment (MoCA) (Freitas, Simões, Alves, & Santana, 2011). The motor and cognitive profile of the participants was diverse (Table 2). Participants had mild to no deficits at shoulder and elbow levels, but broader deficits at hand level. P1 and P3 presented mild deficits, P2 and P5 moderate deficits, and P4 had severe deficits. All the participants presented some level of spasticity but P1 and P5 were the ones with increased tone and movement resistance. Also, P5 showed difficulties to actively extend fingers (open the hand) due to spasticity, needing help in most of the tasks and P4 presented significant difficulties with manual dexterity.

Table 2. *Participants' demographics, cognitive and motor profiles.*

	Gender	*Age*	*Time post-stroke (wks)*	*Stroke type*	*Schooling*	*Computers experience*	MoCA	FMA	ARAT	MAS	*BBT (s)*		Dynamometer *(kg)*	
											Paretic	**Non-paretic**	**Paretic**	**Non-paretic**
P1	Male	51	17	Haemorrhagic	4	No	11	51	56	1+	30	36	8	12
P2	Female	76	3	Ischemic	4	No	13	39	36	1	19	22	4	6
P3	Male	76	7	Ischemic	4	No	15	40	50	1	19	32	4	9
P4	Male	80	32	Ischemic	4	No	20	33	13	1	0	41	8	26
P5	Male	54	80	Ischemic	4	No	21	54	29	1+	3	49	25	57

2.4 Outcome Measures of the Study

The measures that were used aimed to quantify the feasibility of the prototype system as a rehabilitation tool, its usability, and the experienced motivation.

- Feasibility measures included the percentage of *success* in each task, *time* to complete the task, need of *assistance* to complete a task, and the *ease* of the task measured through a 7-points Likert-scale ranging from 1 (Very difficult) to 7 (Very easy), right after each task.
- Motivation was measured through a Portuguese version of the Intrinsic Motivation Inventory (IMI) (Fonseca & de Paula Brito, 2012). This is a shorter 18-items version from which we used the domains of Interest/Enjoyment, Perceived Competence, and Effort/Importance. Additionally, the level of engagement in each individual task was measured through a 7-points Likert-scale ranging from 1 (Disliked very much) to 7 (Liked very much), right after each task.
- Usability was measured through the Portuguese version (Martins, Rosa, Queirós, Silva, & Rocha, 2015) of the System Usability Scale (SUS) (Brooke, 1996). Additionally, we registered the difficulties experienced by the users during the interaction.

2.5 Experimental Procedure

Data collection was done in 2 different sessions, the first one for the motor and cognitive assessment (~60 minutes), and the second one for the tasks and self-report questionnaires (60-90 minutes). In the first session, participants signed the informed consent, followed by the motor and cognitive assessments performed in a random order. In the second session, the participants started by receiving a brief introduction on how the system worked. Participants were informed of the importance of not occluding the objects from the camera during the interaction. Subsequently, participants performed each task in a randomized order. For each task, multiple iterations took place to test its feasibility using different objects to train power grasp, lateral grasp, tripod grasp and strength. Before each task, the therapist demonstrated it to ensure that the participant understood it. After each task, participants reported on enjoyment and ease of the task using the 7-points Likert-scales. Plasticine and putty were only used with *Slide* and *Fill the figure* tasks. At the end of the session, the SUS and the IMI were administered.

2.6 Data Analysis

Due to the small sample size, only descriptive statistics were used. For each measure, values of central tendency and dispersion are provided. Interval type of data are presented through their mean and standard deviation (Mean±SD), and ordinal data as median and interquartile range (Median (IQR)).

3. RESULTS

3.1 Feasibility
We assessed feasibility through total task time, ease, success as the percentage of participants that completed the task, enjoyment (Table 3) and required assistance.

3.1.1 Time.
Regarding the time needed to complete the tasks, *Paint* and *Follow the line* were not strongly affected by the grasp type. Instead, *Maze* took longer with the tripod grasp, *Fill the figure* with the lateral grasp, and *Slide* with the power grasp. However, overall, all grasping activities had similar average times, ranging between 66-82 seconds. For strength training, therapeutic putty/plasticine and pinch pins had opposite effects in *Fill the figure* and *Slide*, being putty/plasticine quicker to use in the former task and pinch in the latter. Strength activities revealed to take longer than grasp activities, mainly pinch pins, which took in average 167.5 seconds.

3.1.2 Ease.
In terms of ease, overall, tasks using grasp were considered of similar difficulty (5 points), and harder when using strength (2.5-4.0 points). However, lateral grasp was the easier grasp in all tasks with the exception of *Follow the line.* Interestingly, data on both *Slide* and *Fill the figure* show a variable difficulty range, 2-6 and 3-6 respectively, depending on the trained skill, allowing for broad difficulty gradation.

3.1.3 Success.
Success rate was not strongly modulated by the type of skill trained (84-100), but it was by the activity. *Paint* and *Follow the line* achieved a 100% success rate with all grasps whereas *Maze* achieved the lowest rate, being the worst case for power grasp (60%). Strength success rates were of 60% for *Slide* and 80% for *Fill the figure*, independent of using pinch pins or putty/plasticine. The remaining activities oscillated between 80-100%.

3.1.4 Enjoyment. When analysing enjoyment for each interactive activity and trained skill pair (Table 3), scores are mostly positive, being the use of parallelepipeds with lateral grasp (5.5) and cones and cylinders with power grasp (5.0) the preferred ones. For strength training, putty/plasticine was always preferred to the use of pinch pins (4.5 vs. 2.75). When looking at each task individually, the most engaging combination for *Paint*, *Maze* and *Fill the figure* was using the lateral grasp, for *Follow the line* and *Slide* the power grasp. Overall, all interactive activities were reported as engaging (5.5/7 or higher) for at least one of the tested combinations.

Table 3. *Completion time, ease, success rate and enjoyment data for each interactive activity and for each trained skill.* ^{Px} *indicates that patient X could not complete the task.*

			PAINT	*MAZE*	*FOLLOW THE LINE*	*FILL THE FIGURE*	*SLIDE*	*MEAN/ MEDIAN*
POWER GRASP	Cones & Cylinders	Time (s)	84.0±49.2	86.3±59.5	32.3±14.4	73.8±46.4	84.5±53.9	72.2±22.8
		Ease	5.0(5.0)	4.0(4.25)	5.0(1.0)	5.5(1.5)	4.0(0,75)	5.0(1.25)
		Success (%)	100.0	60.0$^{P2, P4}$	100.0	80.0^{P4}	80.0^{P2}	84
		Enjoyment	5.0(3.0)	5.0(2.5)	6.0(1.0)	4.5(1.75)	5.5(1,75)	5.0(1.0)
LATERAL GRASP	Parallelepiped	Time (s)	94.4±58.0	73.0±31.2	29.3±7.0	111.6±78.9	22.1±12.8	66.1±39.4
		Ease	5.0(1.0)	4.5(3.25)	4.0(2.0)	6.0(2.0)	6.0(1.0)	5.0(1.75)
		Success (%)	100.0	80.0 ^{P2}	100.0	100.0	80.0^{P2}	92
		Enjoyment	6.0(2.0)	5.5(1.75)	5.0(3.0)	6.0(2.0)	4.0(2,25)	5.5(1.5)
TRIPOD GRASP	Cylinders	Time (s)	91.4±37.5	121.8±97.6	47.8±24.9	95.0±34.7	55.0±37.0	82.2±30.6.3
		Ease	5.0(1.0)	3.5(2.0)	4.0(3.0)	5.5(1.5)	5.0(1.0)	5.0(1.5)
		Success (%)	100.0	80.0 ^{P2}	100.0	80.0^{P3}	80.0^{P2}	88
		Enjoyment	5.0(1.0)	4.5(2.0)	4.0(1.0)	3.0(1.0)	4.5(1.25)	4.5(1.25)
STRENGTH	Putty & Plasticine	Time (s)	-	-	-	104.5±44.2	89.0±55.0	97.0±11.3
		Ease	-	-	-	4.0(3.0)	4.0(2.0)	4.0
		Success (%)	-	-	-	80.0^{P4}	60.0$^{P3, P4}$	70
		Enjoyment	-	-	-	5.0(3.0)	4.0(1.0)	4.5
	Pinch Pins & Cubes	Time (s)	-	-	-	265.0±138.6	70.3±62.4	167.5±137.9
		Ease	-	-	-	2.0(1.0)	3.0(0.75)	2.5
		Success (%)	-	-	-	80.0^{P4}	60.0$^{P2, P4}$	70
		Enjoyment	-	-	-	3.0(1.0)	2.5(2.0)	2.75

3.1.5 Assistance.

Assistance during task performance was provided when needed with three different purposes: movement facilitation, difficulties in manipulating an object (due to the object's characteristics), and interaction problems. The most frequent assistance was movement facilitation, with all patients except P1. Assistance was provided mainly at shoulder, elbow extension and fingers extension/positioning, as well as verbal/touch cues for movement facilitation and avoiding body compensations and undesired postures. P1 and P5 needed assistance using cylindrical objects in the *Maze* task.

3.2 Motivation

To measure motivation, we used the Portuguese version of IMI and the Likert scale. We used only three sub-domains of IMI, rated in a range 1-5 (Interest/Enjoyment, Perceived Competence and Effort/Importance) indicating enjoyment of the system (3.5±1.2), with a slightly lower yet positive sense of competence (3.3±1.0) and increased levels of effort (3.8±0.4). Overall, the total score of the questionnaire was 3.5±0.8 in 5.

3.3 Usability

To measure usability, we used the SUS and our observations. The reported SUS ranged from 25 (below poor) to 72.5 (good), with a mean of 46.1±18.2, corresponding to poor usability. SUS data do not seem to relate to schooling, MoCA, ARAT or MAS, but P1 and P5, who reported the highest usability scores (55.0 and 72.5 respectively) also had the highest FMA scores and reported the highest perceived competence in IMI (4.0 and 4.8 respectively) and were the youngest participants.

Our observations during the performance with the interactive tasks can be grouped in three domains:

- *Interaction.* Some objects have tendency to fall, turn over or tilt, such as small size cylinders, parallelepipeds and smaller cubes, becoming more difficult to detect by the system. In addition, there is a tendency to use movements associated to the affordances of the objects in some tasks, like in *Paint* or *Maze*, where participants tried to drag instead of pulling. Some tasks required a minimum reaching to accomplish them, hence, adding the ability to change the position and limits of the interactive area would improve accessibility.
- *Software.* The current technical implementation of the system relies on a camera with an unobstructed view of the interactive surface. Participants need to be instructed to avoid the occlusion of the interactive objects, which impacts tracking and interactive activities negatively. Some tasks need additional feedback and guidance about the task's next step, knowledge of performance and of results when using objects. This task was also extremely cognitive demanding for P1 and P2, the patients with lower MoCA (11 and 13, respectively).
- *Comprehension.* The complexity of the system and of some tasks, in particular for the participants with lower MoCA, required multiple explanations until an acceptable level of performance was achieved.

4. DISCUSSION

Here we presented a pilot study to explore the viability of a system that uses tangible objects of different shapes and materials to interact with virtual tasks designed for upper limb rehabilitation after stroke. The objects wereselected to train hand grasping and strength, although the interactive tasks are designed to also address other domains such as coordination and dexterity. At the level of feasibility, all interactive tasks scored 80-100% success rate in at least one of the tested modalities, supporting their viability. This is encouraging considering that the resistances and sizes of objects selected for each participant were chosen to be challenging based on their motor profile. Moreover, the exploration of the different pairs of combinations interactive task-and-training skills revealed that tasks can be adjusted in difficulty and completion time, which can be exploited to address the different therapeutic needs of each patient. Strength tasks typically took longer than grasping tasks, particularly when using pinch pins that required grasping a cube with a pinch and releasing it in the desired place. Strength activities were also considered harder than grasps since these activities were more complex and required grasping and releasing combined with hand strength. Hence, strength tasks using putty/plasticine and pinch pins had lower success rates (70%). In contrast, lateral grasp was considered the easiest for interaction. In fact, the specific size and height of the parallelepipeds contributed to their physical stability and consequently were better detected by the camera, which increased the participants' sense of competence. Some participants -those with more functional difficulties- required some level of assistance by the therapist during the interaction. Directed assistance can be beneficial for facilitating muscle activity and movement, and exposing participants to new and correct patterns of activation/movement (Donaldson, Tallis, & Pomeroy, 2009; Hunter et al., 2017). Nonetheless, there is room for improving the feedback guidance delivered during the interaction.

Regarding motivation, the IMI (3.5±0.8) revealed that participants were motivated when interacting with the system. In addition, reported motivation levels for all interactive activities were on average high. Interestingly, these results were modulated by the patient's ability to perform the tasks. We observed that older participants and with lower FMA scores were less motivated, with a lower perceived competence and interest. This was particularly evident for participant P2, who had the lowest motivation score in IMI. Her motor and cognitive deficits made it very challenging sometimes, resulting in failing to finish activities. Nevertheless, these results are in line with results observed in technology based studies with chronic stroke, specifically on what concerns interest/enjoyment and the sense of competence (Colomer et al., 2016).

In terms of usability, we obtained a low average SUS score but with a high variability. Other system where tangible objects were used to interact with a virtual environment obtained higher usability scores (79±7.54) (Colomer, Llorens, Noé, & Alcañiz, 2016). However, the sample of that study had on average a considerably higher motor function (FMA=50.2 and BBT=22.4). We also need to consider that a single usability score was provided for all tasks and configurations tested, analysing the system as a whole and not its individual tasks. Consistent with the motivation data, it seems to relate to the functional capacity of the participants. P1 and P5 were the participants with greater mobility in upper limb (FMA) and also those that reported higher usability scores. It is also interesting to point out that both were the youngest participants. Although all participants reported no previous computer knowledge, age could have played a role. The fact of usability was lower for persons with lower motor skills in the tested configurations does not necessarily imply that the system has a poor usability for them, since task difficulty can be graded through task selection, grasp/strength selection and the material/object properties of it. Moreover, SUS is focused on the autonomous use of a system, and our proposed system is not designed for being used without supervision. Lastly, it is important to highlight that the system was tested without any prior exposure to the technology on a population without previous computer experience.

An important limitation of this study is the small sample size which only allows us to assess general feasibility of the approach and user motivation. However, as results are promising, we intend to increase the sample with a broader spectrum of profiles allowing for a better understanding how to exploit the different characteristics of the proposed tangible interactions. We also identified that interaction and performance could be improved through additional feedback, sounds and/or visual hints. In addition, the study also indicated the preferential use of specific objects to minimize software and interaction issues. Finally, in the future, tasks will incorporate different forms of content and pace to improve motivation and the graduation of difficulty (Hung, Huang, Chen, & Chu, 2016).

5. CONCLUSIONS

This study proposes a novel contribution for the exploitation of the affordances, shapes and resistance properties of tangible objects in an interactive setup, using task mechanics designed for motor rehabilitation with stroke survivors. Data show that tasks are feasible and engaging, even for first time users. Our findings show that grasping training activities worked better than strength training ones, however, both were satisfactory. Nevertheless, there is a need to improve self-efficacy through better object selection, feedback mechanisms and object tracking. Also, we want to add software adaptation mechanisms in the tasks to improve motivation and usability for those stroke survivors with more functional deficits.

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A user-centred design approach to the development and evaluation of a mobile app as a communication aid for deaf people of Cyprus

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ABSTRACT

Communication is a daily challenge for deaf people. People with severe or profound hearing loss face daily communication problems mainly due to the language barrier between themselves and the hearing community. Their hearing deficiency, as well as their use of sign language, often makes it difficult for them to use and understand spoken language. Cyprus is amongst the top five European countries with a relatively high proportion of registered deaf people (0.12% of the population: GUL, 2004). However, the lack of technological and financial support to the Deaf Community of Cyprus leaves the Cypriot Deaf people unsupported and marginalised. Despite advances in communication aid technologies, there is currently no technology available that supports Cypriot Sign Language (CSL) or real-time speech to sign language conversion for the Deaf people of Cyprus. This study implemented User-Centred Design methods to explore the communication needs and requirements of Cypriot Deaf people and develop a functional prototype of a mobile app to help them to communicate more effectively with hearing people. A total of 76 deaf adults were involved in various stages of the research. This paper presents the participatory design activities (N=8) and results of usability testing (N=8). The study found that users were completely satisfied with the mobile app and, in particular, they liked the use of CSL videos of a real person interpreting hearing people's speech in real-time and the custom onscreen keyboard to allow faster selection of text input.

1. INTRODUCTION

Trying to perceive the speech of a hearing person is often hard and exhausting for people with severe and profound hearing loss (Munoz-Baell & Ruiz, 2000; Kuenburg, et al., 2015). Even if the hearing person articulates well, it is still difficult for a deaf person to maintain effective communication; they often have to depend on other non-deaf family members or friends who take the role of interpreter whenever they have to communicate with hearing people (Kyle & Cain, 2015; Hadjikakou et al., 2009). The communication problems faced by deaf people are primarily associated with the use of language; their mother tongue may be Sign Language (SL), whereas the first language of hearing people is a spoken language. In the general community, hearing people are unlikely to know SL, and deaf people cannot always understand the spoken language. This inability to communicate effectively is an obstacle for deaf people not only in their social life, but it also affects their employment, education and healthcare (Compton, 1993; Luft, 2000; Nunes & Pretzlik, 2001; Ubido, et al., 2002, Sirch, et al., 2016).

According to the World Health Organisation (WHO), almost 5.3% of the world's population have a hearing loss greater than 40 decibels and, specifically within Cyprus, there are more than 1000 people with severe and profound deafness (CFD, 2017). Cyprus ranks amongst the top five European countries with regard to the percentage of population who are Deaf, with 0.12% of the population registered as deaf (GUL, 2004). Although Cyprus is a developed country, the government of Cyprus provides no financial support to the Deaf Community of Cyprus (Hadjikakou et al., 2009). Furthermore, due to only recent recognition of Cypriot Sign Language as the official sign language of the Deaf of Cyprus, it is not supported by any of the current communication aid technologies.

1.1 Existing real-time STT/STSL mobile technologies for deaf users

In recent years, various technologies have emerged to support communication between deaf and hearing people. One of the most recent commercially available communication aid technologies for the deaf is "Uni"; a portable device that converts American Sign Language to speech, and speech (English spoken language) to text and enables users to create and upload custom signs (Epstain, 2015). Key advantages of the device is that it can be used on the move, and offers real-time interpretation of SL and spoken language to hearing and deaf individuals respectively (MotionSavvy, 2017). However, it requires use of a tablet device that is too big for the user to hold with one hand while using the other hand to communicate, and it does not include facial movements or expressions, which are important elements for the interpretation of the signs (Woll, 2001; Elliot & Jacobs, 2013).

In 2012, a mobile device called ASRAR was proposed by a team of researchers (Mirzaei, et al., 2012). ASRAR recognises the speech of a hearing person and converts it into text for the deaf user to read. It also consists of a camera and a face recognition software, which are used to capture the face of the speaker and display it on the device's screen. In addition, the deaf user can type texts using an integrated keyboard to communicate with the hearing person. ASRAR proved to be over 85% accurate in its speech to text conversion and the majority of the users expressed their interest in using ASRAR system as a communication aid.

A mobile-based application supporting communication between deaf patients and pharmacists allows the pharmacist to input text which is then translated into SL (Motlhabi, et al, 2013). The information given by the pharmacist is presented on the mobile screen via video enabling the deaf person to get detailed medical instructions as well as to take the correct medicine. However, the application does not enable the deaf user to communicate back to the pharmacist.

Ava is a mobile app that enables deaf people to host group conversations with others and offers real-time captioning for each member of the conversation. It can also be used in a one to one conversation in which the speech of the deaf user's interlocutor is converted to text (Ava, 2017). However it does not present the content in signing, requiring the deaf users to read in English. Furthermore, it does not enable the deaf users to respond either by interpreting their SL or by allowing them to write something using a custom keyboard. Furthermore, it requires all members of the group conversation to install the application even if they are not deaf and they are required to pay a subscription to use the application effectively and be invited into a group conversation.

A more recent mobile application called LifeKey was designed to enable deaf people to report an emergency event quickly without the need of relying on a non-deaf person. A custom onscreen keyboard allows the deaf user to summarise the emergency by tapping through different categories (type of incident and exact location within the area). The users can also set up a custom introduction to state their identity and send it automatically along with their location. LifeKey supports also voice-to-text and text-to-voice conversion for the communication between the deaf person and the emergency staff (Slyper, et al., 2016). This, however, requires the deaf users to be capable of reading and perceiving possibly complicated text content.

It is apparent that deaf people have limited support in their everyday communication with hearing people. Additionally, it is noted that none of the existing mobile apps offers comprehensive real-time speech to sign language conversion, requiring the deaf users to either read text content, which is often inaccessible for many of them, or understand SL presented by 3D animated hands and not a real interpreter, which is not the ideal way of presenting SL (Wauters, et al., 2006). Finally, it is noticed that the Greek language and CSL are not supported by any of the existing mobile apps. Consequently, the development of a mobile app that can act as a portable deaf interpreter and offer a comprehensive support at anytime and anywhere is indispensable for the deaf people of Cyprus. Such an app could contribute greatly to their social life as well as their independence, since it will enable them to better engage in communication within society.

1.2 Objectives and requirement considerations

The purpose of this study was to explore the communication needs and requirements of deaf adults in Cyprus and to identify how a mobile app could help them to communicate more effectively with hearing people. During initial discussions with members from the Cyprus Deaf Federation (CDF), they described communication as a barrier to their social life and healthcare, and commented that they generally experience a lot of impatience from hearing people when they try to communicate with them. Since mobile phones are ubiquitous and allow users to perform tasks in a mobile context, it was proposed that a mobile app could act as an affordable portable interpreter, which could convert spoken language into text and SL and similarly, text into speech.

For the development of a functional prototype, the needs and requirements of deaf users were taken into consideration and informed the design and evaluation process. The characteristics and unique competencies of users were studied through both primary and secondary research. It was noted that one of the major problems that the mobile app would have to deal with would be the weak writing and reading comprehension skills of the Deaf (Marschark & Harris, 1996; Kyle & Cain, 2015). To overcome these issues, a custom onscreen keyboard was developed that includes pre-defined phrases, words, personal information and other categories of text which allow the deaf user to construct sentences more easily than with a traditional keyboard. Additionally, a dictionary of SL videos was developed to enable speech to SL conversion so that the deaf users could better perceive the spoken language.

1.3 Ethical Considerations

Pre-lingual deaf people have a considerably limited comprehension of words and sentences. To ensure that the participants were fully aware of the purpose of the study, the data captured, the use of the data, and their rights, an interpreter was present throughout the study to explain and clarify every detail and enable the deaf participants to ask questions if necessary. In addition, the presence of an interpreter made communication with the participants more accessible and helped them to express their opinions and views about the mobile app. Finally, to minimize participants' strain, the questionnaire was formulated with brief, concrete questions and open questions were avoided as much as possible. Two interpreters as well as two post-lingual deaf members were consulted, in order to avoid overly complicated and abstract language while developing the questionnaire, the information sheets and the prototypes.

2. APP DEVELOPMENT AND OUTCOMES

2.1. Approach

Both qualitative and quantitative methods were used in the research. Action Research aimed at addressing the social problems identified by the user community, was combined with a user-centred design approach to involve users in the design and evaluation of the app through all stages of an iterative product development process. This approach was taken as both methodologies focus on users, their involvement in an iterative process, and the evaluation of actions/design solutions by the users themselves (O'Brien, 2001; W3C, 2004). Figure 1 illustrates the entire process, participant involvement in each stage and outcomes generated to inform the product development. Due to space limitations, only the participatory design and usability testing stages are detailed here

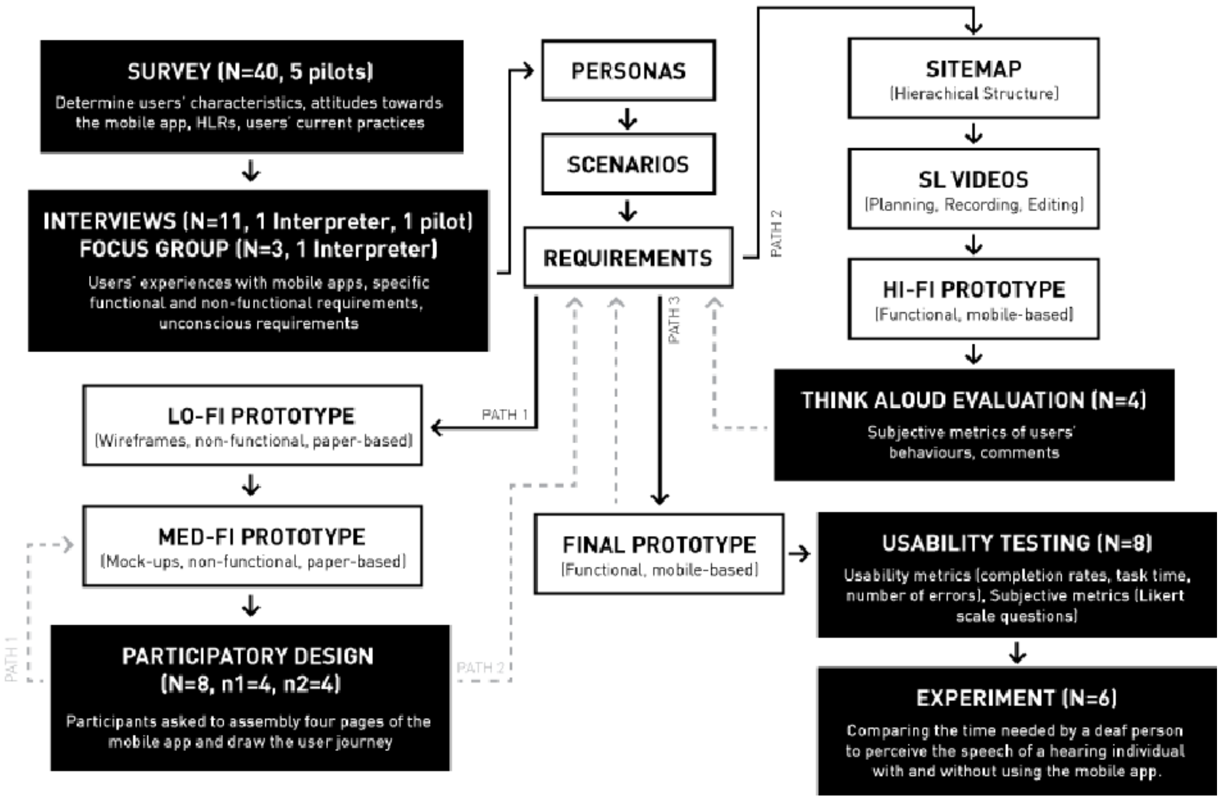


Figure 1. *Overview diagram of the product development process, including user involvement at different stages and the methods used for the data collection, design and evaluation of the prototypes.*

2.2. Participatory Design

Upon specifying the user groups and their requirements through data gathering, the project moved to its second phase; the creation of design solutions. Before developing the initial prototype, design principles and guidelines were considered and the list of requirements was updated accordingly (Google, 2014; Benyon, 2014). A low fidelity prototype was then created and discussed informally with a deaf user. This paper-based representation included draft sketches of the app's navigation and layout (Figure 2, left). Feedback from the deaf user was then incorporated into a medium fidelity prototype showing the look and feel of the app (Figure 2, right). Two participatory design sessions were then conducted through which pairs of users commented on design features, sequencing and overall appearance of the mobile app.

Figure 2. *Prototype development of the mobile app: lo-fidelity prototype with comments about the structure and the elements (left); initial medium fidelity prototype used in the first participatory design session (right).*

2.2.1. Participants.

For the design and evaluation of the medium-fidelity prototypes two participatory design sessions were conducted with four participants each. Eight participants were selected using convenience sampling on the basis of availability. Two couples were invited to the first participatory design session (two representing Target User Group 1 and two representing Target User Group 2)[1]. Two of these were aged between 29 and 39 years and the other two between 40 and 50. Two participants were male and two female. One member was severely deaf whereas the others were profoundly deaf. A family of three pre-lingual deaf members and one hard-of-hearing member was invited for the second participatory design session. In this group two participants were aged between 40 and 50 years and the other two were aged between 18 and 28. One participant was male and the three were female. Three of the participants were severely deaf while the other had moderate hearing loss. An interpreter was present in both sessions to maintain an effective communication between the participants and the researcher.

2.2.2. Materials.

Medium-fidelity prototypes were created using Adobe Illustrator software and printed out at the size of a mobile phone device. They conveyed all of the app's characteristics such as fonts, colours, arrangement and structure, content etc. Sixteen empty mobile screens were printed (one for each page) and displayed on large sheets of white paper using re-usable adhesive to allow participants to change the sequence order of pages. User comments and required changes were noted next to the corresponding page (see Figure 3).

2.2.3. Procedure.

The four most critical pages were reduced to separate design elements (icons, boxes, pictures, inputs, etc.). The participants were then given the elements of each page one by one and were asked to assemble them on an empty mobile screen. They were then asked to put all the pages in order, beginning from the landing page, to create a possible user journey. Finally, they were encouraged to share their thoughts and opinions on how the pages should be ordered and explain their reasoning. The comments and changes derived from the first participatory design session were implemented in the app design prior to the second session.

[1] The initial data collected process identified two Target User Groups for the app: Target User Group 1 represents deaf users who have reading and writing difficulties and Target User Group 2 represents those who do not experience such difficulties.

Figure 3. *The outputs of the two participatory design sessions: first session (left); second session (right). The two groups of participants assembled the mobile screens and created a user journey. Their comments and opinions were written on the white space as well as on specific screens.*

2.2.4. Results.

The changes requested by the participants were mainly non-functional and fed directly into the design and development of the high-fidelity prototype. One non-functional requirement derived from the first participatory design session was to change the main colour of the app to blue (the colour of the international symbol of the deaf). Other changes related to the sequence order of inputs in the login pages and the background colour of the SL videos; the users requested light blue instead of black. The requirements specification document was updated according to the new requirements.

2.2.5. Functional Prototypes.

Based on the updated requirements specification document, high-fidelity and final prototypes were created using the Apache Cordova framework (Apache Cordova, 2017). The prototypes are native mobile apps, designed and tested on an Android Samsung S5 device. An example is shown in Figure 4.

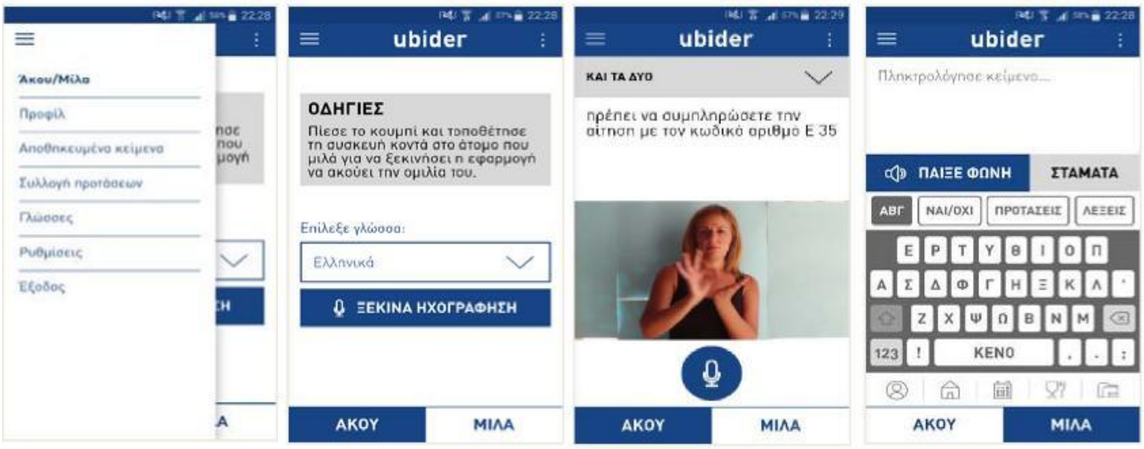
The mobile app includes three major features requested by deaf people through the data collection process:

1) The "Hear" section where speech is recorded and converted into either text only, SL only or both text and SL;

2) The "Speak" section, where a custom keyboard enables the deaf user to type texts using pre-defined words and phrases, which can then be converted into speech;

3) Text storage, allowing users to create texts using the custom keyboard and save them for future use. This enables users to prepare what they want to communicate in advance and use it whenever they want to.

The custom keyboard through which the text is composed includes eight different categories of text options (letters, yes/no, phrases, words, personal details, address details, days & months, food & drinks), six of which were operational in the final prototype, allowing the users to type faster.



(a) Menu (b) "Hear" section (c) Text and SL output (d) "Speak" section

Figure 4. *Example pages of the final interactive prototype used for the usability testing and the experiment.*

2.3. *Usability Testing*

Usability testing was conducted on the final prototype where users were asked to perform five tasks using the application and then complete a short rating scale questionnaire. The time taken to complete a task, the number of tasks completed and the number of errors, were recorded. The users were also observed during the usability testing to provide insights about their behaviour and difficulties.

2.3.1. Participants.

Eight users were recruited to take part in the usability testing. Four of the participants were considered to be "design aware users" since they took part in the first participatory design session, and the second group of participants were novice users. Both groups had equal number of users representing target User Group 1 and target User Group 2. Equal number of female and male users were selected.

2.3.2. Materials.

A task sheet comprising five evaluation tasks was created and a data collection sheet was used to note the time taken for task completion, the number of errors in each task and additional comments if needed. A timer was used to measure the time taken per task and a video camera to record the hand movements of the users and the mobile screen. A semi-standardised questionnaire was developed and used for measuring six subjective usability metrics (appearance, terminology, app capabilities, usefulness, ease of use, satisfaction). The questionnaire consisted of different 7-point Likert scale questions and two open questions about the most liked/disliked aspects of the app.

2.3.3. Evaluation tasks.

The users were asked to complete the following tasks using the final prototype:

- Sign up to Ubider.
- Communicate with the waiter to order a meal.
- Add details to your profile.
- Write and save text for future use.
- Use the saved text to communicate with a clerk in the Social Insurance office.

2.3.4. Results.

All participants successfully completed all tasks with non-critical errors. Some tasks were inherently more difficult to complete than others, as reflected by the average total time on task. Task 2 took the longest and had the most errors, as it required the participants to a) communicate with the waiter, b) order food and c) confirm it. Some participants were writing faster than others and this was also observed by comparing the times on the second task of the third participant (more than 4 minutes) with the fourth participant (less than 2 minutes). The third participant was comparatively slower than the others, however, this was not due to errors but because she was typing at a slower pace compared to the rest of the participants. In addition, she was also a user representing Target User Group 1 (experiencing reading and writing difficulties) and reported that German was her first spoken language, so it would be easier for her if the app offered an option for German language as well.

After task session completion, participants rated the app on six overall measures. Each measure included a number of 7-point Likert scale questions (0 – Strongly Disagree and 6 – Strongly agree). All of the participants (100%) agreed that the app is useful and satisfactory. Most of the participants (87.5% n=7) agreed that reading characters on screen is easy. Seven out of eight (87.5%) participants agreed that the terminology used is always relevant to the task and that the app is designed for all levels of users; however, some participants suggested the simplification of some of the features and provision of more than one way to find something within the app.

3. DISCUSSION

Advances in smartphone technology enables automatic speech recognition powered by deep learning neural networking (Google, 2017), which can be used for speech transcription and automatic SL presentation to allow deaf users to understand the speech of the people around them. The interactive prototype of the proposed mobile app utilises technologies such as the Google Speech API (Google, 2017) to recognise voice and convert it into text. An algorithm was then developed to convert that text into synthesised SL videos to help deaf people with low literacy skills to perceive someone else's speech and communicate with them. In order for the mobile app to work effectively, internet connection or the use of mobile data is required. Slow connectivity can affect users' experience; hence, the use of the simple STT feature can be beneficial in those situations to save data and increase bandwidth.

3.1. Attitudes of deaf users

Through the earlier data collection in the project, thirty-six of forty participants (90%) expressed a need for a mobile app as a personal interpreter. A small percentage of participants (10%) did not want to have such an app, mainly because they were used to communicating with hearing people in their current, traditional way. This, however, could also be inferred as a lack of trust towards the use of technology instead of a real interpreter for communicating with hearing people. Similarly, the interpreter who was present through the study, commented that, from her experience, deaf people would not easily trust a mobile app for communication with hearing people without having someone next to them to reassure them that what is transcribed is correct. Consequently, it is important to test the app in various contexts and with more users before making it generally available.

The eight deaf users who took part in the evaluation of the interactive prototypes exhibited positive attitudes towards the app. They expressed considerable interest in the overall utility of the app and offered a number of recommendations for improvements. This was their first time using a mobile app that converts speech into CSL and text into Greek voice and they were particularly excited by this. Their responses reinforce the potential value of such an app as a positive benefit to users, and confirms their need for communication support.

3.2. Usability and significant features of the mobile app

In order to ensure that a product or a system is usable, the aspects of effectiveness, efficiency and satisfaction need to be measured and examined (ISO, 1998). The results attained through the usability testing showed that the app is effective and that participants were completely satisfied. However, further evaluations should be carried out with more participants and different settings in order for the overall usability to be ensured.

Evaluation of interactive prototypes of the mobile app with users from both Target User Groups, identified that the most useful feature of the app was conversion of speech to SL. Users with reading difficulties required such a feature to allow them to better understand a hearing person's spoken language. Further development of this feature, providing the facility for streaming speech recognition to allow the users to have non-stop speech to SL conversion while the hearing person is still speaking, would be beneficial to the users.

Another feature that was considered important and valuable to the users was the custom onscreen keyboard with categories of text. Users were amazed when they saw their personal information, and other categories of words and phrases, ready to be used in the keyboard. Users with writing difficulties described the keyboard as particularly helpful. Additionally, the fact that they could type text using the custom keyboard and save it for future use was something that excited them too. This feature would allow them to communicate faster and could eliminate the need for pen and paper based back-and-forth writing for communication with others.

Finally, the presentation of synonyms of words on the speech transcription to allow deaf users to understand the meaning of an unknown word used by the hearing person, was another important feature of the proposed mobile app. The CSL lexicon is not as rich as that of the Greek language; therefore, undoubtedly, deaf users will see words that they would not recognise. Consequently, such a feature could enable them not only to understand the meaning of those words but also to learn them.

4. CONCLUSION

The study applied a user centred design approach to the development and evaluation of a mobile app to support communication between Deaf and Hearing people. Members from the Cyprus Deaf Federation (CDF) took part in data collection, iterative design, and evaluation of app prototypes from lo-fi and medium-fidelity through to a functioning demo version. The project cycle was iterated four times and five prototypes were created in total. The integration of multiple methods enabled the researchers to gain in-depth understanding of the research problem, user characteristics and requirements, and direct feedback from target end users. Further development and testing of the mobile app is required to ensure validity and reliability of the results. More experiments should be carried out to test how the mobile app performs in noisy environments and to identify any other functional issues affecting its usefulness. However, it is concluded that such an app has the potential to offer greater independence to deaf users by reducing the need for them to rely on the presence of someone to act as an interpreter to support their completion of everyday activities. Feedback of 100% user satisfaction from the study participants indicates high potential for this technology to support the Deaf people of Cyprus to engage more effectively in communication within society and achieve social acceptance.

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iSenseVR - Toward a low-cost virtual reality solution for exposure therapy in busy environments

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ABSTRACT

This paper presents the research outcomes from a pilot project which investigates the use of Virtual Reality through smartphones in order to empower people with hidden disabilities to overcome stress eliciting situations by experiencing controlled exposure to busy environments in digitally reconstructed airport areas from the comfort of their own safe environment.

Following a participatory design and a usability testing, a semi-controlled 7-day longitudinal study aiming at assessing the responses of our targeted users, was conducted. Results revealed the enthusiasm of participants for such innovation applied to the airports context, although some cyber-sickness symptoms were punctually experienced.

1. INTRODUCTION

Many individuals with Autistic Spectrum Disorder (ASD), acute sensory hypersensitivity, mental health conditions and anxiety experience extreme difficulties with heightened noise and/or crowded situations within environments. These sensory cues can act as social barriers, impeding them doing what most may consider as everyday activities.

Although strategies such as Social Stories™ which consists of a sequence of images along with situation descriptions (Karayazi et al., 2014; OHandley et al., 2015); and organised pre-visits of facilities as a reasonable adjustment, are already in place to familiarise those who live with hidden disabilities with critical places, they are often not enough to increase individuals' confidence as they do not contribute effectively to desensitise from environmental stressors. Thus, there is a need for a more "out-of-the-box" approach.

Virtual reality (VR) consists of an immersive computing experience which empowers an individual to interact within a digital responsive environment (LaValle, 2016). VR can induce presence, the psychological sensation of being present in a virtual environment, which arises from a coherent association between users' perceptual responses to the narrative and immersion (Slater, 2003). Immersion and presence in VR are believed to enable triggering of strong emotional responses (Wilson and Soranzo, 2015; Miller and Bugnariu, 2016) and more particularly the physiological components of anxiety, capable of provoking psychophysiological arousal in all individuals (Diemer et al., 2014). In addition, previous research has shown that VR has high degree of acceptance among users who are typically subject to distress in stress eliciting situations (Newbutt et al., 2016a). For these reasons, VR is considered as a promising facilitator of exposure therapy for the improvement of psychological wellbeing offering opportunities to tackle mental and developmental disorders such as acute stress (Serino et al., 2014), Post-Traumatic Stress Disorder (PTSD) (Botella et al., 2015), dementia (Garcia-Betances et al., 2015), anxiety disorders (Diemer et al., 2014) and ASD (Grynszpan et al., 2014; Maskey et al., 2014; Miller and Bugnariu, 2016; Newbutt et al., 2016b).

VR exposure therapy allows the controlled delivery of sensory stimulation (Maples-Keller et al., 2017). It has demonstrated to be at least as effective as conventional exposure therapy for certain types of disorders (Morina et al., 2015; Botella et al., 2015). However, when traditional exposure therapy becomes complex to set up due to difficulties to control specific environmental cues, VR offers opportunities for highly controllable settings empowering sensory exposure with the presence of the therapist, which would not be possible otherwise (Maples-Keller et al., 2017).

Although, VR presents interesting alternatives to support traditional strategies for tackling anxiety and stress induced by mental and developmental disorders, such advances should be more practically applied rather than being limited to the laboratory settings (Grynszpan et al., 2014). This implies artists, technologists and professionals in the field must endeavour to solve the challenges associated to interventions that are not only effective, but also accessible and usable by most (Grynszpan et al., 2014). One of the possible challenges consists of the limited accessibility of the VR technology in terms of price. Effectively, while recent technological advances are currently contributing to the wider commercial acceptance of VR in gaming, immersive VR technology such as cutting-edge computer-ready Head Mounted Displays (HMDs), still relies on relatively expensive equipment investment and is therefore not yet affordable by most. In contrast, modern smartphones, already owned by many, offer incredible opportunities for designing affordable experiences, building upon reliable graphical capabilities, stereoscopic and spatial audio cues, and head tracking interaction using pre-embedded gyroscopes.

This paper presents a pilot research which investigates the use of VR provided through mobile technology to help individuals with hidden disabilities and mental health conditions to access public places which many consider to be everyday activities. We have designed an experiment to assess the value and potential of iSenseVR, a proof of concept of a VR application for Android smartphones, which aims to familiarise and desensitise individuals with hidden disabilities to busy environments such as Aberdeen International Airport, by gradually increasing environmental stressors in VR throughout repeated use from the comfort of their own safe environment.

2. METHODS

2.1 Participants

7 participants (5 females, 2 males) ($M_{age} = 36.571$, $\sigma = 17.709$) were identified among 25 individuals with hidden disabilities, who were recruited across the UK, using contacts found by Friendly Access, a social firm which promotes reasonable adjustments across society for individuals with hidden disabilities. The inclusion criterion of the study was the ownership of a VR-ready Android smartphone with technical specifications similar or above to a Samsung Galaxy S6, which was released in 2015.

Among the 7 participants, 5 live with anxiety disorder and 4 with depression; 2 suffer from PTSD; 2 individuals have ASD and 2 others have Asperger Syndrome. Finally, one participant experiences severe learning difficulties and none experience seizure activities. All participants reported to be frequent game players on computers and mobile devices, and to be novices using VR.

All participants were asked to fill in an online consent form which presented the objectives of the study and informed them about their rights as participants. In addition, they were instructed about the experimental procedure and the risks typically associated to the use of VR.

2.2 Apparatus

iSenseVR is a non-commercial mobile application for Android VR-ready smartphones. It aims to help individuals with hidden disabilities to develop tolerance to the environmental stressors that are typically found in busy environments. It provides gradual sensory exposure in digital reconstructions of environments that cannot be controlled. Aberdeen International Airport kindly accepted to be a case study.

The application was developed building upon interactions between user-centered interaction design and software engineering design methodologies. We have engaged with different cohorts of end-users to co-design and assess all virtual environments in iSenseVR, to propose sensory realistic experiences (Poyade et al., 2017a). Initially, 26 volunteers with hidden disabilities across Scotland helped identify those typical environmental stressors in busy environments that often lead them to experience high levels of anxiety and stress.

Standardised design methods in the fields of systems and software engineering allowed producing a uniform description of customer needs and requirements for virtual environments. Sixty-six user and system requirements were generated using System Modelling Language (SysML) (Figure 1), providing basis for a unified description of the functional and interaction design of the application using Unified Modelling Language (UML).

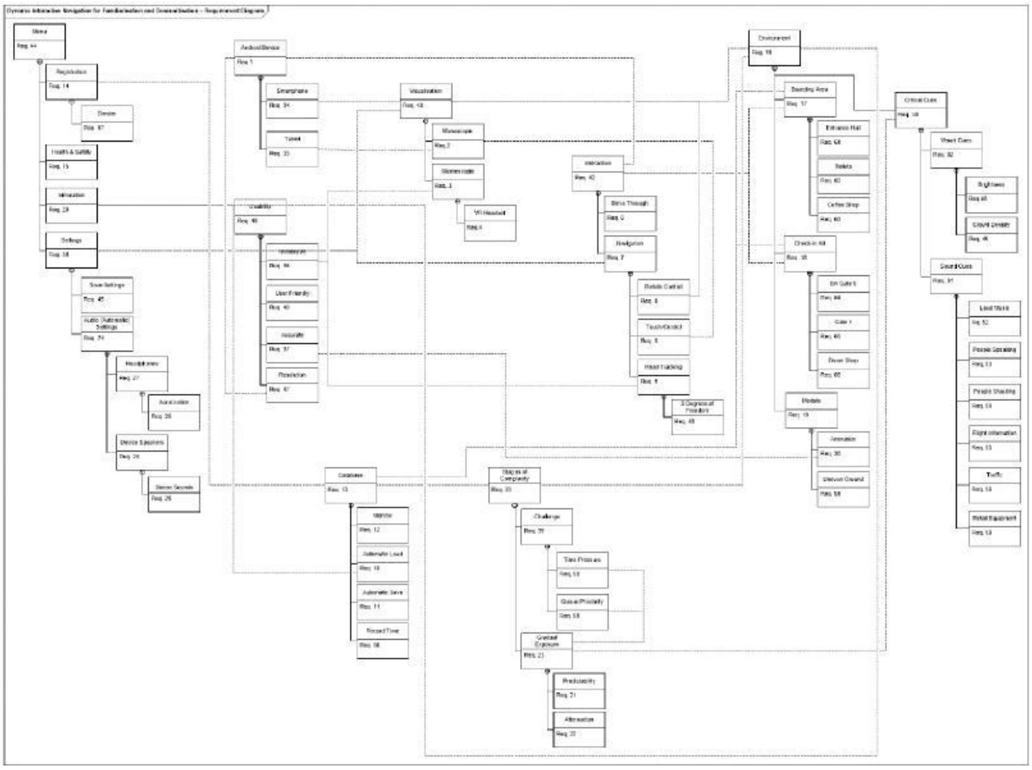

Figure 1. *iSenseVR Requirements Diagram*

iSenseVR was developed for Android mobile devices using Unity 5.6, a cross-platform game engine widely used in the video game industry, however further research iterations will aim at providing a development compatible with VR-ready IOS devices. It provides a series of immersive experiences in digitally reconstructed airport environments that allow exposing individuals with hidden disabilities, in a controlled manner, to critical sensory cues such as ambient sounds (e.g. loud shop music, conversations, announcements and equipment noises) and crowds. In addition, the application supports stereoscopic visualisation, audio spatialisation and head tracking using the Google VR SDK for Unity.

The application initially requires the user to undergo a series of sensory attenuated experiences within each environment. Four environments have been digitally reconstructed and populated with animated digital characters (Figure 2): (a) the entrance hall; (b) a café; (c) gender-specific toilets; and (d) a boarding gate.

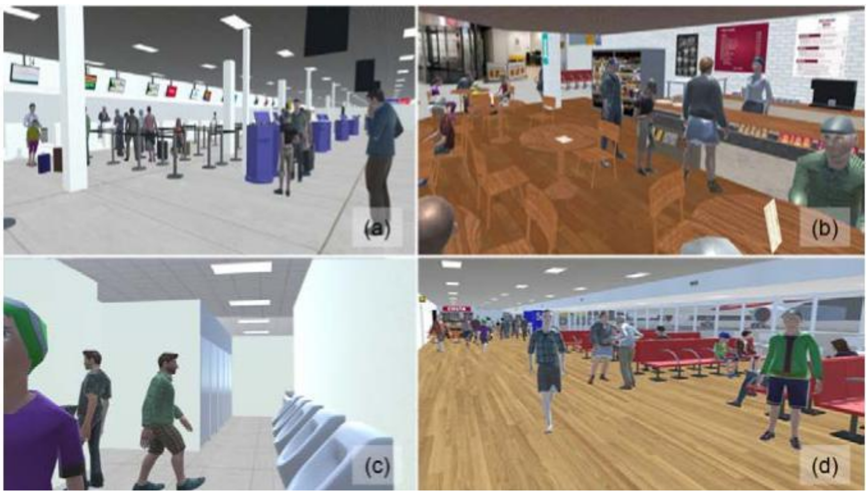

Figure 2. *Digitally reconstructed environments in iSenseVR.*

On launching an environment, the user is randomly driven through one of three possible paths, making each use less repetitive. Each path describes a motion pattern for the user's point of view within the environment. Although paths are fixed, the user can still explore the environment rotating its point of view on 3 degrees of freedom. Paths last no more than 3 minutes in order to minimise users' boredom and cyber-sickness (Davis et al. (2014)). On completion of a path, the user is removed from the virtual environment and presented with the main menu interface.

The gradual increase of environmental stressors ensures each environment becomes more challenging throughout repeated use. This increase is managed by a database located on a remote server. This database assigns a level of complexity per environment for each user. Levels of complexity are associated to pre-set configurations of the audio landscape and the density and activity of the crowd in each environment. On launching an environment, the crowd component is diversified by randomly loading the required amount of animated digital characters from an extensive preloaded collection of characters.

In total, 7 levels of complexity were defined for each environment. The level of complexity of each environment increases when users complete a path, demonstrating their capability to tolerate the displayed sensory cues.

The usability of the application was tested with 11 postgraduate students from the Glasgow School of Art, with no previous experience in VR (Poyade et al., 2017b). They were required to experience each of the aforementioned environments with no sensory attenuation through a Samsung Galaxy S7, while sitting down.

Overall, students were enthusiastic using the application, finding it very intuitive and provided valuable information that helped enhance user experience. Some felt a little eye strain, although no cyber-sickness was experienced.

In this pilot study, participants were required to use their own headphones and smartphones, and download iSenseVR from a temporary link on Google Play Store to install it on their device. Although different models of Android smartphones were used, all were equivalent to or newer than the Samsung Galaxy S6.

After consenting to take part into the study, participants received a Virtual Reality Scope Headset for Smartphones (Figure 3), an affordable and reliable device in which they can mount their smartphone, so they could use the application in VR from a safe and reliable place.

Figure 3. *Virtual Reality Scope Headset for Smartphones (L5.99).*

2.3 Procedure

Participants were asked to use the application on a daily basis for 7 consecutive days, using their smartphones mounted on the VR headset and their own headphones. They were required to attempt to complete one level of complexity for each environment every day, ensuring they were exposed to increasingly challenging environmental cues. They were informed they could plan their daily exposure as they wish, by either experiencing all environments in one session or spreading them throughout the day in case they felt overwhelmed. Each experience lasted no more than 3 minutes, so to minimise loss of interest, discomfort, and side effects typically associated to VR.

Participants were asked to set their smartphone to half volume and recommended to remain seated ideally in a swivel chair and under supervision if support was required, while immersed in VR.

The daily use of the application was reported in an external server allowing researchers monitoring the dedication and progress of each participant through the several levels of complexity for each environment.

2.4 Data Analysis

On completing the experiment, participants were required to rate a series of statements using a typical 5-point Likert Scale: (1) Strongly Disagree; (2) Disagree; (3) Neutral; (4) Agree; and (5) Strongly Agree. Statements aim to inform about the usability of the system and the quality of the interaction, audio samples and visuals. In addition, participants were encouraged to provide comments to support their responses.

Mean values and standard deviations were calculated for each statement, and building upon a Theme-Based Content Analysis (TBCA) (Neale and Nichols (2001)) alike approach helped classifying ordering participants comments and reporting them in a consistent way.

2.5 Ethics Approval

Ethical considerations and safety concerns of participants were paramount to this research, considering the possible negative effects of visualisation through HMDs highlighted by previous research (Sharples et al., 2008), and to the panels of hidden disabilities and symptoms that participants were dealing with in their daily life. This study followed "Principles of Consent" as outlined under Adults with Incapacity (Scotland) Act 2000. This research is non-Clinical Trial of an Investigational Medicinal Products. This legal framework covers many aspects of research and governs the inclusion of adults with incapacity in research in Scotland. Prior to this study, institutional ethics approval was obtained from the research office at the Glasgow School of Art.

3. RESULTS

All participants but two were able to use iSenseVR throughout the whole testing period. Effectively, two participants mentioned experiencing cyber-sickness symptoms and therefore opted for withdrawing from the study after 4 days (Table 1). Overall, participants seemed enthusiastic concerning their experiences in VR, qualifying the application as "excellent app", "a great idea", and "a brilliant tool". Although, in the overall, participants moderately enjoyed their experience ($M = 3.286$, $\sigma = 1.113$). Among those participants who completed the study, no major differences of enjoyment were noted ($M = 3.6$, $\sigma = 1.14$).

All participants who pursued the study but one achieved all levels of complexity in all environments (Table 1), and were using iSenseVR for an average total time of 4284.2 seconds ($\sigma = 829.36$) over 7 days (Table 2).

Table 1. *Levels of complexity completed by users as recorded on the database.*

User ID	Entrance Hall	Café	Boarding Gate	Toilets
1	Level 7	Level 7	Level 7	Level 7
2	Level 7	Level 7	Level 7	Level 7
3	Level 6	Level 6	Level 3	Level 6
4*	Level 3	Level 3	Level 3	Level 3
5*	Level 4	Level 3	Level 2	Level 3
6	Level 7	Level 7	Level 7	Level 7
7	Level 7	Level 7	Level 7	Level 7

* *Withdrawn participants*

Table 2. *Participants total exposure time to each environment in seconds.*

User ID	Entrance Hall	Café	Boarding Gate	Toilets
1	1439	1360	1211	693
2	1054	1114	1027	607
3	891	935	704	538
4*	351	378	315	200
5*	620	402	211	219
6	1427	1481	1357	810
7	1381	1325	1374	693
Mean	1023	999	886	537
σ	428	452	483	239

* *Withdrawn participants*

Overall, all participants felt confident using the application (M = 4.286, σ = 0.756) finding it easy to use (M = 4.429, σ = 0.787) and intuitive (M = 3.857, σ = 0.9). They felt comfortable wearing the headset (M = 3.857, σ = 0.9). Overall, they did not experience much eye strain (M = 2.143, σ = 1.345), fatigue (M = 2.429, σ = 1.512) headache (M = 1.571, σ = 1.134), or dizziness (M = 2.429, σ = 1.813). However, experiences in virtual environments were reported to be a bit disorientating (M = 3.143, σ = 1.215), with the two withdrawn participants experiencing nausea and dizziness ("it made me feel dizzy", "it made me feel a little sick"), that are consistent with typical symptoms of cyber-sickness.

Participants mentioned feeling psychologically engaged within environments ("I felt as if I was there", "It felt like super natural"), suggesting they experienced realistic immersion and high degree of presence in VR. Although they appreciated the changing narrative throughout repeated use allowed them to build up the density of the crowd and sounds ("I get a bit scared by these noises in real life in busy places so it definitely helped me and each day slowly got busier/more noises"), and change the storyline of their experiences ("I liked that over the week it built up the levels of people, noises and changed the surroundings and routes taken each time I used the application"), they suggested the provision of more realistic cues as denser crowds with more natural use of animations throughout environments ("the sceneries needed to be much busier for a more realistic experience") and enhanced interaction paradigms ("I could not actually control the movement", "little boring as I couldn't interact", "I'd have liked to explore some things in the environment more") could eventually contribute improving user experience in the digital environments.

Although remaining participants felt moderately more confident going into busy environments after 7 days (M = 3, σ = 0.707), all participants concurred iSenseVR "would be really beneficial for a lot of people with hidden disabilities" and "could actually help over time". They would thus recommend it to others (M = 4.429, σ = 0.535) ("it would be really beneficial for a lot of people with hidden disabilities") as the experience was perceived to "be so useful to do if going to airport for first time", and "would definitely buy this app if it came out" as some reported that it" could actually help over time".

4. DISCUSSION

People with hidden disabilities such as autism, learning disabilities and mental health problems are far more likely to experience high levels of discrimination, isolation, fear, anxiety, unemployment and poverty. Environmental stressors such like sounds, light and crowds can become huge barriers to independent living.

This research provides a draft of a methodological and technological framework to support the design of immersive VR applications for Android smartphones, aiming to empower those who live with hidden disabilities and mental health conditions to overcome their barriers through repeated rehearsals of a critical situation in a controlled digital environment, from the safety of their home. Our project consists of a demonstration that VR on smartphones mounted on affordable headsets allow people to experience realistic exposure to busy situations in digitally reconstructed airports areas.

Overall, our evaluation reported positive responses from participants and infatuation for the application of VR in the context of busy environments as airports. Although due to a limited sample of participants, our findings need to be carefully considered, they seem to be consistent with previous research outcomes, showing a high degree of presence and acceptance among users (Newbutt et al., 2016a; Newbutt et al., 2016b). Participants felt a little disorientated while visualising digital environments through HMDs, and two of them experienced cyber-sickness symptoms, consistently with indications from previous research outcomes (Sharples et al., 2008).

Consequently, enjoyment was moderately reported, suggesting both, the seriousness of the stress and anxiety elicitation from the simulated situations despite the gradual exposure to sensory stimulation, and the limitations of passively guided navigation leading possibly to disorientation and cyber-sickness. This must be taken into consideration in further research to aspire for a more effective design of an attenuation strategy resulting in a more enjoyable and interactive experience able to tackle user's discomfort.

Our main research outcome, iSenseVR, contributes effectively to the practicality of VR exposure therapy, by bringing it outside laboratory settings towards one's safely considered environments and making it therefore more accessible to most in terms of cost and technical requirements. In that way, our approach is aligned with the recommendations made by Grynszpan et al. (2014) for the design of more accessible interventions. However, the lack of accompanying therapist obliges us to recognize the limitation of our approach, and disqualify, for the moment, iSenseVR as a tool for genuine controlled exposure therapy intervention for helping people with hidden disabilities in order to help them to manage better their anxiety and stress in busy environments. Nonetheless, this does not impede us hypothesising the adequacy and effectiveness of our approach to complement already in-place strategies for reasonable adjustments in airports (Karayazi et al., 2014; OHandley et al., 2015), in further research

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5. CONCLUSION

This paper presents the outcomes of a preliminary evaluation of iSenseVR, a proof of concept of a VR application for Android smartphones, which enables the gradual exposure to environmental stressors in busy places. Results highlighted high user acceptance and increased sense of presence within digital environments. Although further improvements are needed to tackle user disorientation and cyber-sickness, and strategies need to be developed to increase users' confidence after using the application, iSenseVR consists of a low cost and user-friendly solution for gradual familiarisation and desensitisation to some of the critical environmental cues that are typically eliciting distress among individuals with hidden disabilities.

However, in the future, iSenseVR aims to become a domestic practical solution to support conventional and experimental exposure therapies for busy environments such as airports. This will be achieved focusing on design refinements in order to enhance interaction, navigation and user's comfort, and by involving therapeutics into a participatory design approach in order to capture their expertise into more effective gradual exposure interventions that can be conducted from the safety of one's place. An evaluation framework will be designed along with therapists in order to assess the internal, external and ecological validity of iSenseVR.

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End-user involvement in rehabilitation virtual reality implementation research: Benefits, challenges, and lessons learned

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ABSTRACT

Despite increasing evidence for the effectiveness of off-the-shelf and rehabilitation-specific active video games (AVGs) and virtual reality (VR) systems for rehabilitation, clinical uptake remains poor. A better match between VR/AVG system capabilities and client/therapist needs, through improved end-user involvement in VR/AVG implementation research, may increase uptake of this technology. The objective of this paper is to review four examples from our collective experience of including end-users in VR/AVG research to identify common benefits, challenges and lessons learned. We apply this knowledge to make recommendations for subsequent user-engaged research design and methods, including evaluation of the impact of end-user involvement.

1. INTRODUCTION

Virtual reality and active video game (VR/AVG) systems are becoming increasingly popular treatment modalities in rehabilitation (Laver et al., 2017), with evidence building to support skill acquisition in a variety of populations (Darekar et al, 2015).Given the diversity of VR/AVG system options, occupational and physical therapists (OTs and PTs) who provide VR-based therapy must engage in complex clinical decision-making about the selection of appropriate systems and games that are congruent with their clients' abilities and treatment goals (Glegg et al, 2014). A recent survey of VR/AVG use and knowledge needs of PTs and OTs practicing in Canada found that 46% had used VR/AVG at least once, but only 12% reported current use, primarily of Nintendo Wii/WiiFIT systems (Levac et al, 2017). Further, 70% of those surveyed wanted more educational resources to help them become familiar with using AVGs in clinical practice. Therapists who would like to integrate VR/AVGs clinically shoulder much of the decision-making burden to ensure a "just-right-fit" for their clients. However, a lack of knowledge about VR/AVG use was one of the most common barriers to using VR/AVGs identified by survey participants (Levac et al, 2017).

Knowledge translation (KT) refers to the process of moving evidence into action to improve the healthcare system and the health outcomes it facilitates for clients (Graham and Tetroe, 2007). KT interventions aim to enhance knowledge or skills to target the barriers and facilitators of change to promote the uptake of evidence (Graham and Tetroe, 2007; Scott et al, 2012). Ideally, both researchers and knowledge users (otherwise known as end-users) are involved throughout the KT process. A few frameworks exist that describe varying levels of end-user involvement. The "Knowledge to Action" framework developed by Graham and colleagues (2006) explicitly describes end user involvement during the "Action Cycle" portion of the KT process. However, the framework falls short of providing direct recommendations about involving users in the "Knowledge Creation funnel" phase. The User Centered Design Cycle is another framework more commonly used in technology and VR development (Lange et al, 2010; Proffitt and Lange, 2013). This Cycle is also less than explicit about when and how end-users are involved in the process, leaving this decision-making to the researchers. Research on user involvement (UI) in software and technology development has demonstrated that nearly 68% of studies reported positive outcomes at some point in the process (Bano and Zowghi, 2015). However, the nature of UI varies tremendously; the "team" of researchers is generally not diverse in expertise, and healthcare practitioners are oftentimes not involved at all (Bano and Zowghi, 2015).

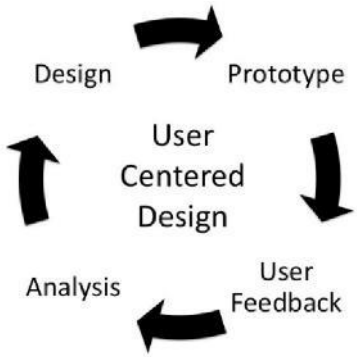

Figure 1. *User Centered Design Cycle.*

Integrated KT, the process of involving end-users within an interdisciplinary team (Gagliardi et al, 2016), is one method to ensure that the expertise and perspectives of the end users are incorporated. An interdisciplinary team can include OTs, PTs, physicians, other allied health professionals, clients, and caregivers. In addition, specific to technology-based integration is the inclusion of industry partners, such as VR/AVG developers and software engineers. This integrated KT approach can be utilized for research evaluating both adoption of commercially available VR/AVG systems as well as the development, testing, and implementation of rehabilitation-specific systems.

Effective and appropriate design for the end-user can promote adherence, improved function and clinical effectiveness (McDonagh and Thomas, 2013). Conversely, poor compatibility with therapists' usage preferences and with clients' abilities and interests and low perceived therapeutic value can hinder adoption (Glegg et al, 2013; McDonagh and Thomas, 2013). For example, although commercial AVG systems present engaging graphics and a great variety of games, they do not allow for necessary control over software parameters to support adequate activity grading for clients with a range of cognitive and physical impairments (Lange et al, 2009). These features can have a significant impact on therapists' adoption of the technology and can influence client motivation to participate in the repetitive interventions required for motor learning (Glegg et al, 2017; Levac et al, 2016). Indeed, without a strong match to user needs and goals, even evidence-based, state-of-the-art technologies will never deliver optimal therapy outcomes.

Therefore, the purpose of this paper is threefold. First, we will outline four case examples involving therapist and client end-users in VR/AVG implementation research. We then describe the benefits to this process, the challenges faced, and the lessons learned. Finally, we provide a set of recommendations for UI in the process of knowledge translation for VR/AVGs in rehabilitation clinical practice.

2. CASE EXAMPLES

2.1 Case 1: Pitfalls of end users as research participants instead of research colleagues

The acquisition of a rehabilitation-specific, engineer-built VR system - GestureTek Health's Interactive Rehabilitation Exercise System (IREX) - by two stroke rehabilitation hospitals was the impetus for this research. To use the IREX, patients stand in front of a green screen and view their image integrated in the virtual environment where they can interact with virtual objects using full body movements. At the time of this research, the IREX was the first and most well-studied motion-capture based gaming technology in rehabilitation. However, it was not being used in these two clinical contexts. To address this underuse issue, and to situate IREX use in a theoretical framework of relevance to stroke rehabilitation, we undertook a KT intervention with the goal of increasing therapist knowledge about how to use the IREX to promote motor learning in adults undergoing inpatient rehabilitation for acute stroke. A secondary goal was to promote increased use of the IREX following the study intervention.

We developed online KT modules introducing therapists to the IREX, reviewing relevant motor learning strategies, and explaining how to use the IREX to promote motor learning principles. We also provided in-person individual and group training in IREX use. Eleven therapists volunteered to participate in the study and delivered a total of 107 VR-based sessions to 34 clients with stroke. Therapists improved their knowledge about motor learning and their scores on the perceived behavioral control, self-efficacy and facilitating conditions scales of the ADOPT-VR, but intention to use VR did not change, with no decrease in the frequency of perceived barriers to VR use (Levac et al, 2016a; Levac et al, 2016b). In addition, we did not see changes in clinical reasoning, use of motor learning strategies or IREX use (Levac et al, 2016a; Levac et al, 2016b). Therapists reported that clients were motivated to use the IREX, but that too many environmental barriers existed for strong clinical implementation of this particular system (Levac et al, 2016a; Levac et al, 2016b).

Subsequent to the study, we recognized that flaws in our study design included the fact that the intended end users (therapists) were not involved in developing the study procedures, identifying knowledge that would be beneficial to support IREX use or development of any of the knowledge translation resources. The study also did not address the practical barriers that were present from before study onset. In particular, logistical factors related to IREX acquisition were a significant issue, including its location far away from the regular therapy room, the fact that it required a 1:1 therapist/client ratio, and its many software issues. Although therapists reported that clients were motivated and engaged with the IREX, the also expressed frustration due to perceived mismatches between games and client therapeutic goals. This experience illustrated that when end-users are not involved at the beginning of the research process to make decisions about *what* they would like to learn and *how* they would like to learn it, and when their needs are not considered in technology integration, well-designed KT interventions can improve knowledge and attitudes but have unfortunate little impact on actual use. As such, targeting both knowledge needs and environmental barriers is important, and should be supported by involving both end-users and the administrators who are in practical, decision-making roles in the research design.

2.2 Case 2: A student train-the-trainer model for knowledge translation

The Rapael SmartGlove (Neofect, Inc.) is a novel technology for hand and wrist rehabilitation. The SmartGlove consists of a wearable, flexible "glove" that contains a gyroscope and accelerometer to track movement wrist, hand, and fingers. The SmartGlove is paired (via Bluetooth) with a touch-screen computer that displays interactive games and movement assessment results. The SmartGlove has been tested in a small study (Shin et al, 2016) and showed promising findings, particularly for those who have experienced a stroke. The company offers a home version for rent by clients and families. The system is touted as being easy to learn and requires minimal training (by both clients and therapists). However, the company only has training materials in beta versions and reached out for input on the materials. At the University of Missouri, the Department of Occupational Therapy provides a no-fee, student-run clinic called TigerOT Clinic. This site served as a prime location for developing and testing training materials for KT relative to the Rapael SmartGlove. Furthermore, the end-users (OT students) were involved in the design of the training materials as well as being the receivers of the training.

Two students learned how to use the Rapael SmartGlove using provided manuals and internet resources from Neofect, Inc. Based on a draft model of a competency assessment, the two students created a competency assessment for clinical SmartGlove use. This version was revised several times through iterative clinical testing. The two students became the trainers for the SmartGlove. The trainers trained five OT students in the clinical use of the Rapael glove for a client being treated in the TigerOT Clinic. The competency assessment was administered before training, after the training, and after five weeks of using the SmartGlove in the TigerOT clinic with the client. At the end of the five weeks, a usability scale was also administered to both the OT student and the client that used the SmartGlove.

Students had an average competency rating pre-training of 1.3/5 (Not At All Competent) and moved to an average of 4.8/5 (Very Competent) both post-training and post-intervention. Further, the OT students rated their clinical decision-making skills relative to the SmartGlove low pre-training and very high after training and after the intervention period. The OT students rated the device 4.4/5 (Fairly Usable) on the Usability Scale and the clients rated the device 4/5 on the Usability Scale. The two trainers reported that they felt very successful in delivering the training and stated that the competency checklist helped to guide the training sessions with OT students. The OT students reported that they felt very comfortable during the training sessions and found it to be more meaningful coming from peers rather than from a company salesperson or a faculty researcher. Thus, a train-the-trainer approach to KT in VR and technology is feasible and potentially effective. A larger study over a longer period of time is currently in progress.

The use of a train-the-trainer model is feasible as an initial step for KT into clinical practice. The two trainers used an iterative process to design a competency assessment that then guided their approach to training. The involvement of the OT students and feedback from the clinic clients further enhanced the process of knowledge translation.

2.3 Case 3: End-user engagement in the evaluation of technology implementation efforts

The FEATHERS (Functional Engagement in Assisted Therapy through Therapy Robotics) system is a rehabilitation-specific system that integrates adapted commercially-available AVG technology (PlayStation2) and mainstream gaming applications from a social media platform (Facebook) using custom-designed computer software (Glegg et al, 2016). The system was designed for use with adults and adolescents with hemiparesis as the result of conditions, such as cerebral palsy, stroke and acquired brain injury (Shirzad et al, 2015). System design requires participants to engage in bimanual upper limb movements in order to interact with the games, while affording them tremendous variety in game selection, and the potential for interaction with peers and their therapist through the social media platform (Glegg et al, 2016). FEATHERS was designed by engineering researchers and computer scientists through a partnership with industry, and in collaboration with community therapists. Clients, families and therapists were engaged as participants in the early design phases of the project to contribute input on the design of the system to meet their needs (Shirzad et al, 2015). Usability testing with clients followed, which led to the refinement of the technology prior to the launch of a clinical trial to evaluate its effectiveness and feasibility as a home-based treatment tool (Glegg et al, 2016).

During this implementation phase, the multi-disciplinary research team included mechanical and biomedical engineers, computer scientists, occupational therapists, a kinesiologist and a physical therapist/knowledge broker. In addition to conducting the clinical trial, the team gathered qualitative data from adolescent and adult participants about their experiences engaging in FEATHERS-based home therapy, and conducted a debriefing session with research team members and community collaborators to share lessons learned (Valdes et al, in press). Key findings of these engagement methods included the identification of advantages of the FEATHERS system, including the variety of games, the option for participants of communicating with the team through various channels, and the technology's perceived therapeutic benefit by some participants. Also identified were challenges associated with the technology itself (e.g. lack of ability to grade challenge or monitor compensatory movements, accessibility), the communication processes in place to support clients/families and therapists in implementing and evaluating the intervention (e.g. accessing technical support, methods of reporting client progress), and the need for additional training (Valdes et al, in press). Each of these areas were pertinent to both the clients and the treating therapists.

While having research team members with clinical backgrounds as part of the research team was extremely valuable, additional input from the therapists implementing the technology as part of the research process, as well as from the study participants, was necessary to gather a comprehensive understanding of the range of barriers to the technology's clinical implementation. A balance of perspectives, and a decision-making process that values each of them in motivating action, can help to guide the refinement of VR/AVG design, as well as anticipate and plan for the mitigation of barriers to the technology's successful implementation.

2.4 Case 4: Knowledge and research outcomes from an interdisciplinary research team and iterative end-user involvement

Following the release of the Nintendo Wii in 2006 and Nintendo WiiFit in 2007, a series of studies were undertaken with therapists and client populations with the aim of identifying the benefits, challenges and appropriate implementation of these technologies in the clinical setting. The research team (PT, OT, psychologist, stroke survivor, computer scientist, biomedical and mechanical engineers) explored the usability of the Nintendo Wii/WiiFit and PlayStation2 EyeToy in the clinical setting with therapists and people with neurological impairments, finding that although commercial AVGs can motivate people to move, a need for more control over the game features and tasks existed, in order to use the technologies within the clinical setting (Lange et al, 2009). The findings from this and subsequent research (Flynn and Lange, 2010) was incorporated into a two-day workshop series that was presented at national and international conferences, universities and rehabilitation hospitals and clinics across the US. These workshops provided researchers, developers, therapists and potential end-users with the basic information they needed to begin to use and/or develop/design game-based technologies for exercise and rehabilitation. These workshops were well received by therapists and researchers.

Since then, we addressed the challenge for creating low cost home-based video game systems for motor and cognitive assessment and rehabilitation for people with stroke, acquired brain injury, spinal cord injury and for older adults at risk of falls. The key advantage of designing these games was to provide the therapist and/or client with the ability to alter elements of game play in order to tailor treatment tasks for individual users and expand the use of these tasks to a wider range of level of ability. The use of games for rehabilitation must maintain the goals of existing therapies, whilst improving motivation to perform therapeutic exercise programs. Through our structured clinical observations, focus groups and user testing with input from clients and therapists at more than 10 sites, we developed and adapted a suite of low-cost game-based rehabilitation tools targeted at improving balance and cognitive rehabilitation (Lange et al, 2010; Lange et al, 2011; Lange et al, 2012; Proffitt and Lange, 2013). The activities within the systems included cognitive tasks and structured static and dynamic balance tasks. The usability of these technologies were evaluated through a series of usability tests at clinical sites run by researchers, the development of a user manual, and feedback gathered following trialling of the system at clinical sites. The VR systems were also evaluated during a six-week individualized home-based exercise program for three people with stroke who had different levels of function (Proffitt and Lange, 2015). The VR system is currently being used in a modified form as an intervention in a multi-center randomized controlled trial for people with brain injury (Krch et al, 2016). The modifications were made because therapists at two sites reported difficulties setting up the individualized programs because there were too many options and it was overwhelming at times.

Therapists are keen to try new technologies but it is important that the right technology is chosen and that therapists are provided with the training and knowledge to adequately implement the intervention in the clinical setting. Commercial systems have a place if they are carefully considered, however, a greater scope exists for the implementation of customizable systems within the clinical setting. Through our work with therapists, we found that therapists want options and control; however, feedback also indicated at times that there was too much control and too many options that could become overwhelming. There is a need to balance what users want with the capacity of the end-users and need for training, time to familiarise and learn a new system, set-up time etc. (difference between plug and play versus needing training to effectively use the system).

Table 1. *Summary of cases including type of VR/AVG, types of end users, and outcomes.*

Case	Target Population	Treatment Setting	Type of VR/AVG	End Users Involved	Outcomes
1	Individuals with stroke	Inpatient stroke rehabilitation	Gesturetek IREX	PT, OT	Improved self-reported knowledge and attitudes No change in intention to use VR No change in VR use
2	Pro-bono clinic clients (uninsured/ underinsured)	Pro-bono student-run outpatient clinic	Rapael SmartGlove	OT students	Successful training Student reported high levels of competence Target population reported good usability of system
3	Adolescents and adults with hemiparesis	Home-based rehabilitation	Adapted PlayStation2 controllers interfaced with existing games on social media platform	PT, OT, participants with hemiparesis	Perceived therapeutic benefit by target population Additional training necessary Awareness of communication preferences of end users during implementation
4	Individuals with stroke, brain injury, amputations, older adults at risk for falls	Outpatient clinic, hospital, home	Commercially available games, customized software paired with Microsoft Kinect®	PT, OT, individuals with disabilities (target population)	Support for use in the clinical setting Training workshops well received by therapists and other end-users

3. BENEFITS AND CHALLENGES FACED

We present a table below that summarizes the benefits and challenges faced in each of the cases. Taking these reflections one step further, we present lessons learned from our experiences to inform therapists and researchers interested in developing and implementing VR systems for rehabilitation.

Table 2. *Summary of factors supporting success, challenges/barriers to implementation, and lessons learned.*

Case	Factors supporting success	Factors that are challenges/barriers	Lessons learned
1	• Motivated end-users • Motivated clients	• Mismatch between technology requirements and setting needs • Practical barriers not addressed	• Involve end users in selection of most relevant VR systems • Design study with barriers and practical issues in mind • Involve end-users in goal setting relative to use of VR, then focus knowledge translation there
2	• Students chose learning outcomes • Train-the-trainer model removes “authority figure”	• Initial training time intensive • Sustainability	• Involving students can further enhance knowledge translation

3	• Range of perspectives from end-users were incorporated in all phases of research process	• Balancing multiple perspectives against feasibility of technology refinement/integration • Time required for additional training for therapists and clients	• Generating knowledge from multiple perspective is necessary • Multiple perspectives can help mitigate current and future barriers to implementation
4	• Commercially available systems accessible and affordable for clinic use • Buy-in from end-users • Involving end-users from the beginning and throughout the research process	• Evaluating and ensuring the technology is appropriate for the end-user • Balancing what end-users want against how the system will be used • Balancing what end-users want with level of complexity of system	• Commercial systems should be utilized strategically • Match the "right" technology to the "right" setting • Too much control/choices in a system can be overwhelming for therapists

4. RECOMMENDATIONS FOR VR RESEARCHERS

Based on our lessons learned from the four cases, we present a series of recommendations for researchers and therapists who plan to develop and use VR/AVGs for rehabilitation. These recommendations can be modified for different practice settings and disciplines.

- *Recommendation 1:* Involve end-users early in, and throughout the development, research and implementation processes (i.e. from conceptualization and design to implementation and evaluation). For example, leverage clinical expertise and client experience to co-develop system design, user-tailored operational manuals and clinical training resources that will facilitate capacity building for end users.
- *Recommendation 2:* Conduct a barriers assessment for implementation that engages all stakeholder groups (e.g. therapists, clients, health care administrators, etc.). This step will help to identify practical strategies that target the most significant barriers from different stakeholder perspectives, as a means of promoting success.
- *Recommendation 3:* Understand health professionals' clinical reasoning processes as a means of informing the features and functionality of VR systems that support game groupings and the ability to grade the degree of task challenge. This will help "match" the technology and the setting (including the demands of the therapist).
- *Recommendation 4:* Consider a train-the-trainer model when working with a target population that is resistant to change or authority. Trainers must develop rapport with end-user groups to maximize buy-in and eventual implementation.
- *Recommendation 5:* Identify champions or mentors in implementation settings to support engagement, training and troubleshooting. Ongoing linkages to the technology developers and researchers may support uptake, and allow for continued knowledge exchange that could inform improvements of the system.

5. CONCLUSIONS

Increasing end-user involvement in VR/AVG implementation research may address issues related to poor clinical uptake. In the VR/AVG context, end-users can be therapists, clients, or technology developers/engineers. This paper presented four case scenarios describing the implementation of different VR/AVG systems and involving a variety of populations, end-users and settings. We illustrate that a better match between VR/AVG system capabilities and client/therapist needs leads to improved end-user involvement in all stages of VR/AVG implementation research. We identified common benefits of increasing buy-in and soliciting early on the knowledge and skills of therapists as well as input from the ultimate end-users: people participating in rehabilitation. We discussed challenges of balancing the technology requirements with the needs and goals of the practice setting and of the end-users. Our set of recommendations for subsequent user-engaged research design and methods span the process of development, research, and implementation. We hope that these recommendations will foster collaborations across disciplines, encourage researchers and therapists to adopt VR/AVGs more readily, and lead to efficacious and effective treatment approaches for rehabilitation clients.

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Gradual and shared immersion in virtual reality exposure therapy

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ABSTRACT

Virtual Reality demonstrates potential to reduce the high dropout rates in exposure therapy. Yet evidence of its efficacy is more mixed for treatment of PTSD than phobia. While this may be down to fewer studies for PTSD, we argue that it might be because conventional approaches replace rather than complement methods of controlling engagement. We report on two approaches aimed at complementing methods of engagement through sharing graduated immersion in evocative stimuli with the therapist. The high-end approach uses Immersive Projection Technology (IPT) to place the therapist and client within the simulation together. Graduation of immersion is achieved through turning on more projection walls. The commodity approach uses VR ready mobile phones that can be held in the hand and later inserted into a headset. This approach is currently being used in the treatment of some of the victims of the recent Manchester Arena bombing. A further novelty is the use of 360 video in the commodity approach. This has facilitated rapid customisation after a terrorist incident, allowing victims to re-enter the stadium in which they were attacked, from the safety of the clinic. This work demonstrates alternative technology solutions for VRET that might overcome the variability in its efficacy when used with more vulnerable clients. It also demonstrates how customised stimuli can be quickly and cheaply gathered after a major incident.

1. INTRODUCTION

Mental health is resourced far less than physical health across the world. For example, UK Spending on mental health care equates to only 11% of the UK NHS budget, despite accounting for 23% of the burden of disease in the UK. It seems likely that the growth in acceptability of mental illness seen in the UK is reflected in a growing number of countries, putting therapist services under pressure across the world. Terrorist and other mass causality incidents are increasingly placing sudden surge in demands. More efficient ways of working are needed to meet this growing and unpredictable demand. Exposure Therapy is the most evidenced treatment for phobia and PTSD, however, it suffers high dropout rate, typically from too low or high engagement. Virtual Reality Exposure Therapy (VRET) has potential to address this, as it seems more engaging to resistant populations and stimuli can be controlled to theoretically manage engagement. VRET has demonstrated clear efficacy across the treatment of phobias but efficacy varies across studies of treatment of PTSD. It could be argued that those with PTSD are in general in more need of greater control of engagement and support from the therapist. We argue that using traditional technologies, management of engagement is hampered by immersing the client alone within the stimuli before they have had help to approach it.

Exposure Therapy (ET) is one of the most evidenced treatments for PTSD (Cukor, Spitalnick, Difede, Rizzo, & Rothbaum, 2009). Yet it suffers a 40% dropout rate, largely as a result of either lack of, or too sudden, engagement of the client (Imel, Laska, Jakupcak, & Simpson, 2013). Reluctance to engage in ET is a key predictor of negative treatment outcomes (Rothbaum & Schwartz, 2002). Seemingly engaging to resistant populations, VRET might help by reducing dropout rates (Goncalves, Pedrozo, Coutinho, Figueira, & Ventura, 2012) and improve treatment outcomes. VRET gives the control of imaginal, and ecological validity of in vivo ET (Goncalves et al., 2012). Under control of the clinician, clients are gradually exposed to evocative stimuli, according to individual needs (Rothbaum & Hodges, 1999). Yet it is the stimuli rather than immersion in it that is graduated. Efficacy has been demonstrated in four independent meta-analyses (Page & Coxon, 2016) and effects transfer to the real world (Morina, Ijntema, Meyerbroker, & Emmelkamp, 2015). However, the majority of the independent studies covered in the meta-analysis where for treatment of phobias. There have been insufficient Randomised Control Trial (RCT) in VRET for PTSD for a meta-study to measure efficacy. Reports of efficacy, including dropout rate, in the treatment of PTSD, have been mixed across studies. Two recent larger RCTs actually showed slightly less efficacy including slightly higher dropout when VRET was compared to a control group undertaking conventional ET (McLay et al., 2017; Reger et al., 2016). It should be noted that the Regar study only used a small set of military scenarios, most of which appear to have been tailored for a tour of duty in a different country. McLay et al., proposed that the reason for the big differences in study results is related to the role of a therapist. The therapists we have talked to worry that conventional technologies hinder traditional methods of controlling engagement.

ET facilitates sustained awareness of a problem in order to rationalise (A Carey, 2010). Both avoidance of (Spinhoven, Drost, de Rooij, van Hemert, & Penninx, 2014) and fixation towards (Van Bockstaele et al., 2014) anxiety-provoking experiences maintains psychological distress, whilst improved attentional control is associated with recovery from mental health problems (Goschke, 2014). Dual awareness between evoked memories and present-moment experience is seen to facilitate exposure in traumatised individuals (Rothschild, 2003). Rothschild shows how therapist use Non-verbal communication (NVC) to mediate a client's attention between the two. Conversely, "immersive virtual environments can break the deep, everyday connection between where our senses tell us we are and where we are actually located and whom we are with" (Sanchez-Vives & Slater, 2005). Traditional VRET uses Head Mounted Displays (HMD) (Sanchez-Vives & Slater, 2005), which block both the present surroundings and therapist from view (Roberts, Fairchild, Campion, García, & Wolff, 2016).

The majority of VRET research has used head mounted displays that do not offer the flexibility and sharing of experience of new commodity headsets, especially those based around phones, or of immersive projection technology that have shown utility in supporting social interaction within simulation. Consumer VR is beginning to facilitate clinical treatment in ecologically valid conditions (Slater & Sanchez-Vives, 2016). This paper describes two, very different, technology solutions to overcome the issue of losing sight of therapist and real world while becoming accustomed to evocative stimuli in VRET. Table 1, sums up these approaches, which are described in detail later. Immersive Projection Technology (IPT) puts people together within the simulation, whereas Augmented Reality (AR) does so without removing the present. Although both have been sparsely used in VRET related studies, e.g. IPT (Pan, Gillies, Barker, Clark, & Slater, 2012), their potential to encourage natural client-therapist interaction is yet to be studied. IPT systems are expensive, take a long time to install and are not generally portable. Traditional IPT systems combine stereo and parallax enabled through viewpoint tracking. Less technical surround projection that does not have these features, is beginning to be used in reminiscence therapy for dementia. Mobile phones have been used with video based media in therapy in the Military Veteran's service hosted by the clinical partner of this paper. However, we are unaware of the prior use of phone based Virtual Reality Exposure therapy.

Table 1. *Comparison of our High end and Commodity systems*

Solution	Technology	Therapist in view	Safe surroundings in view	Graduated immersion	Non-verbal communication
High end	Immersive projection technology	Always	Clearly within a display system / real world objects can be brought in	Gradually turning on more projectors	Full throughout
Commodity	Phone based VR	Until client ready to "go it alone"	Until client ready to be fully immersed	Held in hand then put in headset and on head	Full until HMD warn

2. RECOMENDATIONS FROM INITIAL CONSULTATION WITH THERAPISTS

Based on the apparent paradox between the importance of dual awareness in exposure therapy and the blocking out if the real world in conventional VR, we have consulted six therapists from a range of backgrounds in exposure therapy. From this we have derived the following recommendations.

Recommendations:

- Client and therapist are in the environment together;
- A familiar and safe environment remains visible in initial therapy;
- The level of immersion is gradually increased;
- The client can move or look away from stimuli that they find threatening;
- The client can approach stimuli in their own time;
- Natural interpersonal space between client and therapist to be maintained and adjustable;
- Non-verbal communication should not be obstructed in early therapy;
- The therapist should be able to see how a client reacts to stimuli and identify which part of the stimuli;

- The therapist can judge when a client dissociates and if the they are fixating gaze on or away from threat;
- Non-verbal communication can be used to bring the client's attention back to the present.

3. HIGH-END SOLUTION – IMMERSIVE PROJECTION

Our high-end solution is a laboratory demonstrator that situates client and therapist together within potentially evocative stimuli, figure 1. The system is based on a VR CAVE. Importantly our display is larger than a standard CAVE, being an octagon with over 5m between opposite screens. Stimuli can be projected on all eight walls and floor or any subset. Stereo is provided through active stereo shutter glasses but can be turned off when not needed. Viewpoint parallax is supported to a single user, the client. Parallax can be disabled to allow both to view from the same stationary perspective. Positional sound is provided to all occupants, for example client and therapist, through wavefield synthesis. We now describe the solution in terms of the above recommendations:

Client and therapist are in the environment together – The client and therapist stand together, surrounded by controllable and potentially evocative stimuli. The client can thus be reassured by the presence of the therapist. *A familiar and safe environment remains visible in initial therapy* – The display system remains clearly visible, for example, edges between walls, tracker and lack of projection roof. Seats can be taken into the environment to replicate the seated situation in a clinic. Other furniture can be brought in. However, the environment will not be familiar until it has been experienced many times. *The level of immersion is gradually increased* – by starting with one projection wall in mono, adding stereo and parallax and then gradually turning on additional walls and floor. Additionally, to facilitate client engagement and feeling of safety, the dose of exposure can be controlled by a client through interface devices, or through communication with a therapist within the feedback loop. This loop might include qualitative methods such as verbal and non-verbal communication, quantitative methods such as questionnaires or psychophysiological monitoring in real time. *The client can move or look away from stimuli that they find threatening* – The display system is 5 metres across and the stimuli can appear to be far behind the screens. Less threatening stimuli can be projected on some screens and some may be turned off. *The client can approach stimuli in their own time* – is facilitated through freedom of movement within a 2.5m radius. *Natural interpersonal space between client and therapist to be maintained and adjustable*; the extra display size allows two people to easily maintain intimate (up to 0.5m), personal (0.5-1.2m) or social (1.2-3.6m) distance. Much of public space (3.6-7.7m) can be maintained by moving to opposite ends of the display, although the application of this within therapy is not obvious. *Non-verbal communication should not be obstructed in early therapy*; the only non-verbal communication that is obstructed is that related to the eyes. This includes gaze, pupil dilation, narrowing or widening and tears. This occlusion can be avoided in early therapy by delaying the use of stereo. Even when stereo glasses are worn, body language and head gaze can be used to judge how *a client reacts to stimuli and identify what part of the stimuli is being reacted to*. For example, when exposed to a virtual height, we have seen and filmed people shuffling and hunched as they edged along what appears to be a suspended beam, figure 1 right. When no stereo is used, interpersonal gaze can be used to reassure the client and the therapist has more non-verbal resources from which to *judge when a client dissociates by monitoring their gaze* and whether client is fixating on or away from threat. The latter is easier when parallax is not enabled. *The therapist can use non-verbal communication when bringing the client's attention back to the present*; the therapist can physically move between the client and threat and/or use gestures along with spoken word to direct attention back to the present.

Figure 1. *Immersive Projection Technology allowing a shared experience in an exposure therapy experiment with a phobic subject. Left) The researcher offers reassurance to the participant. Right) The participant's body language shows fear as she shuffles along a board past a drop.*

4. COMMODITY SOLUTION – VR CAPABLE PHONE

The commodity mobile solution uses VR capable phones. These allow 360 video or virtual worlds to be experienced while the phone is held in the hand or warn within a VR headset. Therapy might start by a therapist showing the client how to navigate the stimuli when the phone is held in the hand. To begin with, this can be done by swiping the finger. The client is then shown how to look around the environment by moving the phone around them. They are shown how to change stimuli, which is described in the next section. Finally the therapist demonstrates how to put the phone into the head-mounted display, put the display on and select and navigate the stimuli through it. Initially, this is all done using neutral stimuli that has nothing to do with what is feared. Once the client has practiced such use, he/she can be encouraged to select and navigate stimuli that might be evocative, starting with the least evocative. The client is encouraged to use the phone in the hand while the therapist watches how they explore and respond to the stimuli, intervening when necessary to reassure and perhaps reground the client.

Figure 2. *Phone-based VR display. Therapists at the Manchester Resilience Hub practice the use of the technology before widening its use with victims of the Manchester Arena bombing. In this practice, therapists take turn playing the role of the client.*

The approach combines Samsung phones with GearVR headset. S7 and S8 edge phones have been used with both versions of the GearVR headset. We now describe the solution in terms of the recommendations:

Client and therapist are in the environment together - While the phone is held in the hand, the therapist and client are completely visible to each other and clearly in the same place. However, that is not the place of the stimuli. Rather the stimuli are seen through a small window held in the hand of the client. *A familiar and safe environment remains visible in initial therapy* – This solution is easily deployed in the clinic, home and neutral environments. The familiar environment is visible to the client until they decide to put on the head-mounted display (HMD). *The level of immersion is gradually increased* – starting with a phone held in the hand, then moved around the head and finally worn on the head. *The client can move or look away from stimuli that they find threatening* – Natural movement can be used to move aspects of the stimuli out of view but the client cannot step away from the stimuli. *The client can approach stimuli in their own time* - The client can't physically walk towards the stimuli but can gradually select stimuli of every more evocative nature. *Natural interpersonal space between client and therapist to be maintained and adjustable* – The phones and definitely the headset lend themselves to the typical seated situation of therapy. However, interpersonal space can be adjusted by moving chairs and changing posture. *Non-verbal communication should not be obstructed in early therapy* – All NVC is clearly visible when the phone is held in the hand but eyes are occluded when the headset is worn. *The therapist should be able to see how a client reacts to stimuli and identify what part of the stimuli is being reacted to;* the therapist might sometimes be able to see what is on the screen of the phone when held in the hand. This will become more difficult when the phone is panned around the head and impossible when worn on the head. Nonverbal reactions will be visible, with the above caveat of eye occlusion when HMD is worn. *The therapist can judge when a client dissociates and if they are fixating on or away from the threat, by monitoring their gaze* – When the phone is held in the hand, the therapist can see if the client is fixating on it or away from it. Given the low field of view, this is a reasonable indication of fixating on or away from stimuli. However, the stimuli may or not be visible to the therapist, as above. *The therapist can use non-verbal communication when bringing the client's attention back to the present* – This is only hindered when the HMD is worn.

5. MEDIUM

Traditional VRET has used 3D interactive computer graphics. This gives high levels of customisation, allows content to be created that cannot easily be collected and increases engagement through integration. However, even the best computer graphics falls short of the realism of video. Furthermore, the creation of new content is typically lengthy and expensive. This has not been too much of a problem where triggers are generic. For example, many war veterans have experienced traumas in similar settings. However, terrorist attacks and other mass casualty civilian incidence can be more diverse. Furthermore, many involved in such incidence feel they want to go back to where it happened but want graduated exposure to prepare them. The wide availability, low cost and ease of use of 360 cameras and VR based phones that can use them, offers an alternative to conventional computer graphics. Footage of the site and even aftermath of particular traumatic incidences can be collected and edited within the timelines of therapy, especially given the cooling off period that is advised before therapy begins. After the Manchester Arena attack, we gathered 360 photographs and video of the entrance foyer in which the attack took place and the escape routes. Videos have included both footage of therapists walking around the space and walkthroughs. 180 panoramic videos have also been collected. Our approaches have both been used with a variety of mediums. Both support interactive computer graphics, 360 video, and the two combined. The high end system also supports free viewpoint video, which is full 3D computer graphics reconstructed from multiple video streams. There is nothing but lack of funding stopping us from porting this to the phones. We have taken the decision not to show pictures of this footage as such might distress readers who may have experienced the incident.

6. INITIAL FEEDBACK FROM CLIENTS, THERAPISTS AND PARTICIPANTS

The high end system was trailed at the University of Salford whereas the commodity system was trailed at The Manchester Resilience Hub, set up to coordinate mental health support for victims of the Manchester Arena bombing. These two systems were then compared to a range of other, more traditional head mounted displays, in a consultancy session involving one war veteran.

6.1 User feedback for High end system

Twenty Seven healthy and fourteen phobic participants have taken part in exposure therapy experiments in the high end approach. No problems of excessive anxiety were encountered. Prefrontal cortex activity as measured through fNIRS showed significant inhibitory learning across three sessions in phobic participants, and these quantitative results suggesting efficacy have been written up in an article under review. Healthy participants took part in an interview following the experiment. The essence of most comments were shared by the majority of participants. The full set of such representative comments is:

"I was reacting as if it was real, and although I was a bit scared, I knew I was safe"
"The simulation was compelling and I enjoyed it, but the task was a bit boring towards the end"
"I was not afraid of falling. I was more fascinated. The depth makes it real"
"I lost the balance in the Pit Room even thou it was not real"
"I was impressed by the graphic. The walls looked real"
"At the beginning, I was a bit scared, but it goes away over time"
"I think the depth and 3d effect makes it look as real. It makes it feel like standing on the ledge"
"I liked the VR so much that I have forgotten I was wearing NIRSport <fNIRS cap>"

No interview was given for phobic subjects. This was because the quantitative data capture was extended and we wanted to avoid participant fatigue. Four unexpectedly contacted us after the experiment giving descriptions of how they had been able to better handle their fears in the real world. Two involved crossing of a bridge, one for the first time, the other, stopping to take a photograph off the side. The other two involved for the first time not feeling fear when descending, in one case a ships ladder, and in the other, a slatted stair case. The participant who crossed a previously avoided bridge, scored the highest on the fear of heights questionnaire. Clearly observable signs of anxiety including shuffling, avoiding looking down, freezing, sweating and shortness of breath, all declined across the three sessions.

One war veteran experienced the high end system running in low immersion mode, the well-known VRET system for war veterans, BRAVEMIND from USC. He was a highly experienced veteran of multiple tours of duty in many campaigns, who had been successfully treated for PTSD. He became very engaged in the experience, talking excitedly about the differences between the modelled Iraq environment and his own experiences. Sweat became noticeable on his forehead and the session was stopped. It is notable that this sweat would likely have been missed if he had been wearing an HMD. In the debrief he expressed much enthusiasm for the approach as a treatment for PTSD in war veterans.

6.2 Feedback for commodity systems

Four therapists and around ten clients at The Manchester Resilience Hub have experienced our approaches. Therapists who have used the commodity approach with victims of the Manchester Arena attack have also been highly positive. They report that the clients take quickly to the technology and seem to enjoy experimenting with its use. No problems have been encountered. Clients have controlled graduation of immersion for themselves and have transitioned through the levels far quicker than expected. All have put on the HMD by the end of the first session with the technology. Interestingly, one of the clients chose to hold the HMD to her face rather than having it strapped in place. The clients consistently said that they felt now able to visit the feared place in real life following the use of the technology.

6.3 Feedback comparing these and other technology approaches

A second veteran, also considered treated in clinical terms, was shown the two approaches as well as a conventional VRET approach using a tethered headset and interactive computer graphics. He again was enthusiastic about the approaches. He suggested, without being prompted or given the background, that the less immersive options be used at the start of therapy and the more immersive towards the end.

7. DISCUSSION

VRET has been widely researched for over a decade and demonstrated efficacy across four metastudies. We have not found any literature directly suggesting problems of over engagement or anxiety caused from the therapist being out of sight. There does seem to be growing evidence that efficacy of VRET is not as straight forward in the PTSD population as it is in the phobic one. This might simply be due to the number of trials. However, the latest RCT was a substantial trial that concluded efficacy was less than conventional exposure therapy. Both the literature and discussions with therapists reveal a mismatch in the kind of client therapist interactions and in particular methods for grounding in the present, between conventional exposure therapy and VRET. We were unable to find literature that attempts either to study this or propose technology solutions that might avoid it. It is notable that the majority of VRET uses traditional Head Mounted Displays and CGI, while immersive projection technology and augmented reality are better suited to shared experience and merging of simulated and real environments.

For the phobic subjects, IPT offered a clear advantage over surround projection that does not incorporate stereo or tracking driven viewpoint. This was because we employed IPT in VRET for treatment of acrophobia, and depth cues are important in giving a strong impression of height. Depth cues might be particularly relevant to other phobias, such as a bird flying into the face. However, for PTSD, depth cues are generally only useful in terms of creating a greater feeling of being there. The feeling of being present in the simulated environment can be achieved, albeit to a lesser extent, without these cues. Furthermore, this feeling might need to be balanced with that of feeling in the presence during therapy and it might be useful to keep the stimuli from seeming too real. Classic IPT does not resemble either an everyday or clinical environment and cannot be considered a familiar setting. While everyday objects can be brought into the environment, being surrounded by screens might be unsettling to people who are already unnerved. Surround projection onto existing walls that does not require stereo glasses or viewpoint tracking might be a better fit to therapy that does not specifically need depth cues. Such technology is already being used in reminiscence therapy for dementia by companies including 4D Immersive. Such an approach seems well suited to the treatment of PTSD within clinics. However, even this simpler variety of projection technology is far more expensive than our commodity phone based solution.

VR ready phones and tablets offer a low cost, highly portable solution that both therapists and clients can learn to use in minutes. It integrates smoothly with both 360 video and computer game engines. While initial use fits well to client therapist interaction, the technology lends itself well to home therapy, once therapist has helped the client gain confidence. 360 cameras offer a way of capture the places that an incident occurred before exposure therapy treatment is began.

Immersive Projection Technology (IPT) puts people together within the simulation, whereas Augmented Reality (AR) does so without removing the present. Although both have been sparsely used in VRET related studies, e.g. IPT (Pan et al., 2012), their potential to encourage natural client-therapist interaction is yet to be studied. However, these systems are expensive, take a long time to install and are not generally portable. Traditional IPT systems combine stereo and parallax enabled through viewpoint tracking. Less technical surround projection that does not have these features, is beginning to be used in reminiscence therapy for dementia.

The two approaches are very different. Augmented reality solutions might fill some of the gap. However, head mounted augmented reality, will for the moment, hide the eyes, which are probably the most important non-verbal communicational resource in therapy. Thus devices that can be held in the hand before warn on the head will not become obsolete with AR. Shared AR with area sensing, such as Tango based systems, would not only allow view of the real environment and company but also virtual assets to be placed around the clinic or living room and approached as one approaches stimuli in the large IPT.

8. CONCLUSIONS

While efficacy of Virtual Reality Exposure Therapy for phobias has clearly been demonstrated to be at least that of conventional exposure therapy, fewer studies of treatment of PTSD show a mixed picture. There may be many reasons for this and we have proposed a new one. Comparison of literature of exposure therapy and virtual reality suggests a paradox between: the importance of dual awareness of present and what is feared ine therapy; and virtual reality's ability to convince that what is simulated is real. Discussing this paradox with a variety of therapists led to a list of recommendations for VRET technology to be used with more vulnerable clients. We presented two technological approaches to VRET that each give affordances to these recommendations. The High End approach used immersive projection technology, whereas the commodity approach used phone based VR. Both allow graduated immersion and high levels of non-verbal communication between client and therapist during initial therapy. Both have been shown to both therapists and treated clients who have provided supportive feedback. The high end approach has demonstrated efficacy in trials with a sub clinical phobic population. The commodity approach is now in use, treating victims of the Manchester Arena Bombing. Early feedback from the therapists suggests this approach is popular with both clients and therapists.

This paper has described Cognitive Behavioural Therapy for phobic participants and clients suffering PTSD. It is notable that mindfulness therapy is in vogue in treatment of anxiety disorders, albeit' s efficacy less evidenced in PTSD and phobic populations. We are seeing a rapid growth in interest in VR for mindfulness. While our approaches and recommendations may be of help in such, the importance of graduating immersion and sharing experience with the therapist may not be as acute. However, we strongly recommend shared low or graduated immersion approaches in any use of VR for dementia. As yet there is no evidence that immersing vulnerable people to quickly in VRET causes a problem, however, RCTs of VRET for PTSD are giving mixed results and concerns of the therapists and clients we have spoken to seem rational. There is thus a need for a clinical trial to test if these concerns are grounded by comparing graduated and immediate immersion. Until these concerns are proved groundless, we believe it prudent that they are listened to. In the mean-time we recommend that those made vulnerable by mental health conditions should not be pushed to immediately go it alone in VR therapy

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Pervasive game design to evaluate social interaction effects on levels of physical activity among older adults

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ABSTRACT

Pervasive electronic games use innovative mechanics to create immersion and promote user engagement, thus being a potentially powerful tool to promote active lifestyles among the elderly. We describe a pervasive game developed to test how design elements can affect older adults' levels of physical activity, using social interaction as case study. Two variations of the game were developed – including or not social interaction – and a feasibility study was performed to evaluate the proposed design and its potential to affect the levels of physical activity of players.

1. INTRODUCTION

As all countries in the world experience the aging of their population (ONU 2015), different strategies become necessary in the pursuit of promoting quality of life among elderly citizens. Over the last two decades, there was a crescent interest on games and gamification processes (Bleakley et al. 2013) for that end. An intimate, indissoluble relationship with play and fun is one of the most fundamental aspects of human condition (Huizinga 1949), and elderly people are obviously no exception to this rule. Based on that premise, new lines of research have surged, advocating that games for the elderly should first be *fun*, and all additional benefits will come as a natural consequence of playing. Indeed, this has been repeatedly observed in previous works (De Schutter & Vanden Abeele 2015).

In this context, an emerging genre that is yet unexplored as a tool to create fun and engaging experiences for elderly people are the so called *pervasive games*. There are several definitions to the term, but the common element is the requirement that these games offer a set of mechanics (game rules) that blends aspects of the real world – for instance, locations, people, objects, *etc*. – with a virtual world – *i.e.*, the world of the game – (Buzeto et al. 2012), thus blurring the edges of the "magic circle" that surrounds the player (Montola 2005). For that reason, games in this category have also been referred to as *ubiquitous* (Björk et al. 2002), *context aware* (Koskinen & Suomela 2006), *mixed reality* (Bonsignore et al. 2012) or even *trans-reality* (Gutierrez et al. 2012).

By mixing realities, these games aim at deeper player immersion, having the potential to be highly engaging. This can be noticed on popular titles, such as Pokémon GO (Niantic 2016), Ingress (Niantic 2013) and Dead Rising 3 (Hamilton 2013). Particularly, since many pervasive games incorporate physical location into their design and stimulate people to walk around, they are specially fit to promote quality of life, since it is strongly correlated with physical activity (Colcombe & Kramer 2003; Larsen et al. 2013; Vagetti et al. 2014). These games also focus on more casual experiences, thus reducing the cognitive load and establishing a smoother transition to introduce novice users to unfamiliar technologies (McGonigal 2006).

Taking these factors into consideration, the general goal of this study is to investigate, from a design perspective, which strategies are more adequate when developing pervasive games for older adults – *i.e.*, we want to find out if there are specific design elements or principles that can be effectively used to create fun, engaging experiences for elderly people, and promote their quality of life.

As any design problem, this is an *ill-structured* or *wicked* problem (Simon 1969). For that reason, our approach was to design and implement an *experiment system* – *i.e.*, a system used to *understand* a problem, not to solve it. Specifically, we used *social interaction* as a case study to develop a pervasive game that allows testing and experimentation, being adaptable and expandable if necessary, allowing for further investigations. We performed a feasibility study to evaluate our system and its suitability for further experiments, such as randomized controlled trials.

2. RELATED WORK

Game design, *i.e.*, design of player experience (Schell 2008), is a relatively recent discipline, even though it applies to any kind of game, not being restricted to electronic systems. Pervasive games, specifically, have been emerging as a research topic in the last decade, with several games made (Buzeto et al. 2012) and some recent works focusing particularly on design (Kasapakis et al. 2013; Buzeto et al. 2014; Kasapakis & Gavalas 2015).

Games for elderly became a research topic on its own in the context of serious games for health (Smith et al. 2009; Garcia Marin et al. 2011). Early works investigating possible challenges when designing for older audiences (Ijsselsteijn et al. 2007; Ogomori et al. 2011; Barnard et al. 2013) identified common physical and cognitive limitations that should be taken into consideration, however, when it comes to game content and motivation to play, there is excessive focus on perceived benefits, without a deeper analysis of potential experiences and emotions sought by the players.

De Schutter *et al.* point out the self-evident, nonetheless often ignored fact that older players of electronic games do not form an homogenous group, but instead, like any other demographic, show highly varied behaviours and preferences deeply influenced by culture, background and both intrinsic and extrinsic motivations (De Schutter & Vanden Abeele 2015). The authors performed an ethnographic study and combined the Uses and Gratifications Theory (Katz et al. 1974) and the Self-Determination Theory (Ryan & Deci 2000), to propose 5 basic profiles of older players (De Schutter & Malliet 2014), generally observing individual adherence predominantly to one of the profiles, with aspects of the others appearing to a lower degree.

Different studies attempted to identify possible preferences of elderly people regarding content and/or genre of the games, primarily using surveys (Carvalho et al. 2012; Cota et al. 2015; Kaufman et al. 2016). These works, however, can offer still only a limited perspective due to varied factors, such as the restriction imposed by the fixed choice of genres – including the definition of game genre itself, which is a disputed topic in the literature – and some of the subjects' answers being based on game descriptions only, not actual gameplay.

More recent studies asked senior citizens to play different kinds of games and then evaluate their experience, focusing on specific styles of game, such as casual games (Chesham et al. 2017). One group of games that is commonly evaluated in research targeting older adults is the class of the so called *exergames*, games in which the player must perform specific kinds of coordinated movements to control the input, sometimes in association with other cognitive tasks (Kayama et al. 2014). Many studies have used different kinds of interfaces for such games, and evaluated the user acceptance of the technology and/or motivation to play (Brox et al. 2017; Meekes & Stanmore 2017). There are also some examples of pervasive games targeting older adults, usually focusing on specific goals, such as cognitive training (Gamberini et al. 2009) and promotion of physical activity using social incentives (Brox et al. 2011).

3. METHODS

Previous works used games to address specific issues in terms of older adults' health – physical activity, social interactions, cognitive skills, *etc*. Those studies focused on *solving* specific problems, thus, the main object of evaluation was how the *presence* or not of the game changed the output. In this work, however, we focus on design, *i.e.*, the focus is on *understanding* the problem, and evaluate how specific design elements can change the outcome, thus the *game itself* is changed to test for those effects.

Using this approach, several design aspects of pervasive games could be investigated, however, as a first step, we chose social interaction, because it has a particularly strong effect on the wellbeing of senior citizens (Lee & Ishii-Kuntz 1987) and is a specially flexible and interesting aspect that can be used to propose pervasive mechanics. To evaluate user behaviour, we chose physical activity levels, since, as described in Section 1, this metric is one of the major factors that can directly affect elderly people's quality of life. Specifically, we are interested on player's average number of steps.

Taking these factors into consideration, we designed and implemented a pervasive game to act as our experiment system and performed a feasibility study do evaluate if the system can be successfully used by the target audience, and if it affects their behaviour. The next sections describe the game design and the study protocol.

3.1. Game Design

The game design process was inspired by Schell's *elemental tetrad* (Schell 2008), that analyses a game based on its *technology* (*i.e.*, the media or devices that enable the game to be played), its *mechanics* (*i.e.*, the rules and possible actions inside the game), its *story* (*i.e.*, the game theme, characters, narrative, *etc*); and its *aesthetics* (*i.e.*, the elements accessible to the player, such as graphics and sounds). A pervasive game is one that incorporates real world elements into one or more of these attributes, in such a way that they actively influence the player's experience (Buzeto et al. 2014). Thus, our designed process aimed at a game that ideally could have any of these four elements changed and controlled to test how they affect the player.

Based on a compilation of existing games (Buzeto 2015), and with the advice of experts who work with elderly people and elderly people themselves, we used an iterative design process to create a pervasive mobile game called *Shinpo* – in Japanese, 神歩, meaning "sacred step(s)" – to be initially played by elderly people in Japan. The basic premise of the game is that the player must collect cards, each of them having an animal and being of certain colour, that indicates the level (Fig. 1). Different animals from the Japanese fauna (or folklore) were used. There is no hierarchy between animals, but levels vary from 1 (violet) to 4 (gold). The goal of the game is to obtain at least one gold card for each animal.

Figure 1. *Examples of cards from Shinpo.*

The game stimulates players to walk around by asking them to collect the cards while visiting locations in the real world – in this case, shrines around Kyoto city (Fig. 2a). Players receive some cards when they enter a shrine for the first time, and, after that, they periodically receive more cards, the quantity and level of which are determined by how much they walked and how many hotspots they visited on the previous days. Once inside a hotspot, a player can see their current cards (Fig. 2b) and also trade a certain number of cards of one level for one card of the next level. Because there are 4 levels, it takes a long time to achieve the game's goal of having all the possible gold cards. By design, players with higher levels of physical activity can win the game faster

(a) (b)

Figure 2. *Screens from Shinpo: (a) world map and (b) hotspot.*

Even though Shinpo deliberately uses specific thematic and abstractions – shrines and card game references – hoping to appeal to Japanese (elderly) people, the rationale behind the design is that collecting items is a widely enjoyed activity by people of different cultures, specially seniors. More importantly, this basic mechanic can be adapted in all elements of the tetrad, since it can be easily transported to different cultural contexts (*e.g.*, zodiac signs instead of animals or coins instead of cards); different rules and interaction strategies (*e.g.*, cooperation, competition, challenges, hierarchies); different visual styles (*e.g.*, traditional, cute, cartoonish); and different technologies (*e.g.*, physical objects, IoT devices). These adaptations, when limited within a closed context, could also be presented simultaneously to different groups of players to control for their specific experience. For instance, the colour schemes or the illustration style could be changed and evaluated for their appeal to different audiences: different players could see different colour schemes or different styles, either statically, based on profiles set *a priori*, or dynamically, based on information such as location, time or weather.

According to our choice for the initial evaluation, a variation of the game was created to include social interaction. Since the nature of the social interaction could also generate different effects on people's experiences, or even on their willingness to interact at all, the proposed mechanisms also account for two types of interactions: those that happen in person, and those that happen exclusively through virtual means. One additional design choice was to focus only on cooperation on this first step (i.e., there’s no competitive element), since it’s more prone to engage people than competition, and is more aligned to the Japanese culture in general. The proposed variation includes these additional rules:

- players have customized profiles to identify them to other players;
- players can see and "like" other players’ actions;
- players can, once per day, leave a card at a hotspot; other players will be notified about it and will receive a copy when they enter that hotspot; the owner is rewarded with additional random cards of same level based on the number of total copies distributed this way;

- hotspots offer challenges that players can join, groups of players must visit certain hotspots within the day to win additional cards;
- in example of direct personal social interaction, if nearby players meet in person, they also receive cards.

3.2. Feasibility study

To evaluate the game, we performed a feasibility study with volunteer community dwelling senior citizens who attend a program run by Kyoto University Hospital that offers weekly sessions of exercise-based cognitive training at a local community centre. The study followed the protocol illustrated in Fig. 3.

Figure 3. *Feasibility study protocol.*

At the beginning of the research, participants answered questionnaires regarding their previous experience with technology (if they have and use smartphones and/or personal computers, how often they use them and what kind of tasks they use them for) and with games in general and electronic games specifically (what kinds of games they play, how often, using which devices and with whom). No previous experience was required to join the experiment, volunteers received a pre-configured smartphone and were given an explanation about its basic operation.

For the first week, they were asked to simply carry the smartphone around, so we could measure the baseline level of physical activity. On the following 2 weeks, the subjects were asked to play the game (social interaction version). Throughout all this period, participants had access to a support desk to clarify any doubts or solve technical problems.

At the end of the study, all remaining participants were asked to answer questionnaires to assess the usability of the game and the smartphone and to report their experience during the game as well as their sense of social presence. The questions were based and/or adapted from the Game Experience Questionnaire (Poels et al. 2007) and translated to Japanese by the researchers. The order of the questions was randomized for each participant and all objective items used 5-level Likert scales of one of two types: agreement level (0=strongly disagree,4=strongly agree) and frequency (0=never,4=always). Positively and negatively phrased questions evaluating the same aspects were included and, in that case of negative questions, the answers were used with the weight of the items inverted. Finally, free answer questions were also included at the end of each questionnaire, so users could report problems and/or difficulties using the game/smartphone and give their feedback about positive/negative aspects of the game.

4. RESULTS

The next sections report the results of the feasibility study.

4.1. Participants

The study successfully recruited 12 participants (F=9) with average age 75 (SD=3.37) and 3 of them (F=2) dropped after the first week. Of the answerers, 7 (58%) had used a smartphone before. Among the people who used a smartphone before, 6 (86%) use it for basic tasks (calls, e-mail, internet browsing) and 3 (43%) access social networks. Also, 7 people (58%) reported using personal computers. Of those, 6 (86%) use it at least 2-3 times/week. Of the participants who use computers, 7 (100%) access their e-mail and browse the internet, 5 (71%) edit documents, 4 (57%) edit photos, and 2 (29%) play games.

For the questionnaire that assessed previous experience with games, 1 person reported playing only non-electronic games, 1 person reported playing only electronic games, and 2 people said they play both types of games. Cited games included Japanese chess, Go, solitaire and mental training games. The respondents use either the PC or a portable console (*e.g.*, Nintendo 3DS) to play. All respondents played at least once a week. One person reported playing with family members (other than their grandchildren) and everyone else reported playing only by themselves.

4.2. Steps and in-game actions

Results for number of steps and game actions for the whole group during the study are shown, respectively, on **Tables 1** and **2**.

Table 1 – *Number of steps of the whole group during the study.*

Wee	Mean	SD	Effect (over
1	22567.	16347.	--
2	24272.	16995.	+1705.7 (7.6%)
3	24393.	14203.	+1826.1 (8.1%)

Table 2 – *Total in-game actions successfully performed during the study.*

Action	Amoun	%
Visit a hotspot	140	72.9
Drop a card	22	11.5
Give a “like” for a card dropped by another player	12	6.3
Meet another player	16	8.3
Join a challenge	2	1.0
Finish a challenge	0	0.0
Total	192	100.

4.3. Usability and game experience

According to the questionnaires answered at the end of the study (Max. Score=4), users remembered to carry the smartphone around most of the time (3.2) and to charge it at night (3.2), and were able to learn its basic operation (2.6). Players were able to understand the game rules and goals (2.1'-2.2) and liked its visual style (2.1), but there were mixed results about learning the game controls (1.1'-2.1). The game music was disliked by most players (1.4).

Players enjoyed the challenge level of the game (2.0'-2.2), this impression was corroborated by some comments on the open questions. Players also report engagement and satisfaction/motivation to play (2.2'-2.8) and enjoyment/fulfilment (2.2'-2.6). There was a general sense that the game stimulates players to explore their surroundings and discover new things (2.2'-2.7), which was also corroborated by some open questions comments. There was strong approval of the game theme (Japanese shrines) (2.7'-2.8). The answers show mixed results for the sense of immersion (1.8'-2.2) and for originality of the game (1.9'-2.4). Finally, as expected, since the game has simple rules, there was not much sense of creative freedom (0.8'-1.8), *i.e.*, of allowing the player to create their own experience.

Answers to the Social Presence Questionnaire – used without any modification from the original (Poels et al. 2007), except for those necessary for translation – report low scores for all items (0.0'-1.13), indicating a weak sense of social presence and involvement with other people. This is coherent with the proportionally very small amount of social interaction related actions (**Table 2**).

4.4. Discussion

The results of the feasibility study show that the choice of theme and visual style for the proposed game was adequate, and that elderly people can understand the game rules and their goals while playing. Participants also felt challenged and engaged, enjoying the chance to explore their surroundings. On the other hand, there might be difficulties when it comes to learning complex controls. Since a significant proportion of the participants had some level of previous experience with technology, and recent evidence shows that this number will continue to grow, we believe that recruiting only people with experience using smartphones may be a good strategy to allow for more complex interactions and motivation mechanisms inside the game.

The weakest point of the design was the proposed social interaction mechanics, that were very rarely used by the participants. We believe this happened because the proposed mechanics require a large number of simultaneous players to be effective, thus a revision of such mechanics taking these findings into account will be necessary for the next steps of this research.

5. CONCLUSION

A deeper understanding of how pervasive mechanics affect older audiences would provide an invaluable tool for researchers and designers aiming at using pervasive games to promote the wellbeing of elderly people, possibly increasing even further both the scope and the effectiveness of such interventions.

In this paper, we use social interaction as a case study to design and implement a pervasive game that allows for such investigation. The game was evaluated for its feasibility and results show that the game was successful in engaging and motivating people, but it must be improved in other aspects. Nonetheless, even though this work focused on social interaction, the proposed design can be adapted in all aspects of the elemental tetrad, and allows for testing of other design elements, not being restricted to this specific domain.

In our future steps, we will improve our design to address the issues identified in our study, and investigate other variations on design, aiming at further expanding our understanding of how design choices can affect player experience and behaviour.

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Utilising object tracking for the performance analysis of difficult airway equipment - A Shape Retention Testing System (SRTS)

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ABSTRACT

Failure to secure the airway on induction of anaesthesia can result in death and disability. Current equipment does not always provide an optimum solution. Most anaesthetists consider bougies essential equipment for safe anaesthesia. Evaluative systems providing accurate objective data assessing bougie introducer performance data do not exist. The Shape Retention Testing System (SRTS) utilises the Intel® RealSenseTM SR300 camera to create an accurate and repeatable testing environment. SRTS collected data will allow anaesthetists to compare device performance that will inform purchase and usage decisions of bougies, ensuring optimum benefit for safe practice.

1. INTRODUCTION

Airway management procedures continue to challenge anaesthetists daily, with serious consequences including death or disability, trauma to the airway, cardiac arrest and hypoxemia (Gannon, 1991). Recommendations have been developed by the Difficult Airway Society (DAS) (Frerk et al., 2015) which includes advice on equipment selection.

Current equipment does not always provide optimum solutions. Recent studies and reviews of various devices have demonstrated that the correct selection of equipment can improve management success rates (Cook et al., 2011; Su et al., 2011). Factors including device construction, material selection and ease of operation, influence the success or failure of airway procedures and need to be considered in purchasing and usage decisions. There are a wide variety of devices available on the market, some are sophisticated and expensive such as video laryngoscopes and fibreoptic scopes and others such as the bougie, are relatively simple and inexpensive.

The standard bougie is one of the most common intubation aids used in practice. Bougies (Figure 1) are long, flexible, relatively narrow rods that have some intrinsic "memory". They can be shaped and directed into the trachea more easily than an endotracheal tube when the laryngeal view is limited. Bougies are commonly used during endotracheal intubation to help guide the insertion of an endotracheal tube into the trachea. They are particularly useful with the management of difficult intubations but must be used with caution to prevent injury.

Figure 1. Selection of Bougies Available Within The UK

There are many versions of bougie introducers available on the market, the most commonly utilised include the Portex® Single Use Bougies (Smiths Medical International Ltd, Kent, UK), SunMed Introducer Bougie (SunMed©, Grand Rapid, USA), InterGuide Tracheal Tube Introducer Bougie (Intersurgical Ltd©, Wokingham, UK), Frova Single Use Introducer (Cook Group Incorporate©, Indiana, USA) and Marshall Single Use Bougie (Marshall Airway Products Ltd, Radstock, UK). However, the original Eschmann Tracheal Tube Introducer *"Gum Elastic Bougie"* (Eschmann© Holdings Ltd, West Sussex, UK) is still considered the gold standard device for use.

Numerous studies have been carried out to assess the use, properties and risks associated with bougie-assisted intubation. Janakiraman et al., (2009) evaluated tracheal tube introducers in simulated difficult intubations, Annamaneni et al., (2003) compared multiple use and single use bougies in simulated difficult intubations, Marson et al., (2014) considered bougie related airway trauma, Jackson et al., (2009) investigated the force required to remove bougies from tracheal tubes and Hodzovic et al., (2004a) (2004b) evaluated various bougies, the effects of tip pressures and placement considerations. These studies have been instrumental in developing guidelines relating to the management of tracheal intubation in adults.

Many of the above-mentioned studies do not use standardised testing equipment with the required accuracy and in some cases do not use the appropriate equipment required to provide precise results. Attempts were made to look at comparative performance within the studies, however these often failed to assess relevant absolute performance and in some cases, such as assessment of memory, the techniques lacked reproducibility and objectivity. The results collected within these studies are therefore only internally comparable or comparable to studies that use the same testing and equipment protocol or setup.

Equipment selection in current practice is largely based on subjective preference, skillset, operator training and cost. Developing testing systems that analyse comparative device performance based on objective and statistically relevant data would be a major advance potentially reducing airway management related complications and improving success rates. Siena et al., (2017) discusses the importance of difficult airway equipment performance analysis and the concept of a Shape Retention Testing System (SRTS) and a Tip Pressure Testing System (TPTS). The research team at Nottingham Trent University (NTU) and Nottingham University Hospitals Trust (NUH) have now constructed these testing systems and protocols. This paper specifically focusses on the development of the SRTS, its functionality and validation.

1.1 System Concept & Patient Benefit

The SRTS is a standardised, calibrated testing system that can provide quantifiable data on the performance of airway equipment and bougies in particular. In addition to individual and departmental purchasing and use decisions, societies and academics can also use this data to inform guidelines for best practice. Currently no testing system exists for the assessment of the shape retention characteristics and properties of bougies; Siena et al., (2017) presented the concept of testing systems to help standardise equipment assessment. These systems must be adaptable, calibrated to collect relevant, reliable and accurate testing data, and function alongside interchangeable components to standardise system setup regardless of the assessed equipment's diameter and length.

Creating a logic-based programming setup with a protocol of standard movements would aid the manufacture of a standardised testing system with calibrated home and reset functions. The capability to alter testing parameters would also create a repeatable testing system adaptable for variable equipment assessment. The camera system must provide accurate camera/video tracking with fixed frame rates and appropriate field of view (FOV) to track bend angles, tip movements, speed of movement and shape retention. Accurate camera tracking data, captured in combination with interchangeable angle measurement grids, would allow the assessment of data over clinically relevant ranges, both pre and post processing.

Ensuring anaesthetists and Hospital Trusts have objective information will help identify optimum equipment selection for use/purchase, thus ensuring measurable improvements in clinical outcomes and success rates. The system has the potential to be of benefit to patients by:

- Identifying devices with the greatest shape retention, thus ensuring procedures are quicker and more efficient with reduced need for multiple intubation attempts.
- Reduce the risk of airway injury, particularly perforation of the airway due to excessive tip pressures.
- Reduce the risk of damage occurring to the teeth because of the anaesthetist trying to obtain a view due to not being able to manipulate the bougie in situ because of poor malleability.
- Teaching/tutoring methods can be improved as training could be standardised for a set of approved equipment, therefore reducing equipment operator experience factors.

1.2 Clinical Need

There are many bougies available, all designed to perform the same task. Each manufacturer's bougie varies, whether this be rigidity, colour, length, diameter, shape retention capabilities etc. However, to date little evidence supports bougie selection other than personal preference or designated hospital suppliers. Mushambi et al., (2016) recently completed a national survey of tracheal tube introducers and the associated complications suggesting the Gum Elastic Bougie (GEB) is associated with the lowest complication rate; the majority of DAS members prefer the GEB. However, with a price point of approximately £30-60, the GEB is more than twice the cost of single use bougies. Hodzovic and Latto (2007) suggests hospitals are less inclined to permit the use of the GEB due to the purchase costs. It is, therefore important to identify suitable single use bougies with optimum performance.

The objectification of physician preference is also an important aspect to consider. Although there is some evidence to support reduced tip pressures and reduced risk utilising the GEB (Hodzovic et al., 2004a; 2004b) there is also an argument that physicians likely chose the GEB due to their tactile feedback perceptions of the device. If the physical properties and tactile feedback of the GEB can be replicated into a disposable device, this would be advantageous; however, the argument could still be presented that Hospital Trusts will still not adopt a device without improved clinical performance evidence and financial reductions.

The SRTS & TPTS will provide information to help inform these decisions. Many single use devices available, especially those from suppliers outside of the UK, have not undergone any formal testing in accordance with the UK's Difficult Airway Society's, Airway Device Evaluation Project Team (ADEPT) principles (Pandit et al., 2011). ADEPT formulated advice underlining evidence-based principles, defining minimum evidence requirements to inform purchasing and selection decisions. The ADEPT guidance protocol concludes:

"All airway-related equipment under consideration must fulfil the minimum criterion that there exists for it at least one source of 'Level 3b' trial evidence concerning its use, published in peer-reviewed scientific literature." (Pandit et al., 2011).

Intubating quickly and safely is imperative to avoid hypoxic injury; therefore, the speed of intubation is critical. Time taken is affected by the laryngeal view and the number of attempts required. Hodzovic et al (2008) evaluated the clinical effectiveness of the Frova single use tracheal tube introducer and found that first attempt success rates fell when the laryngeal view was poor. Success rates of bougies are affected by device characteristics and construction, including factors such as rigidity, shape retention, flexibility, bend angle and grip position. All these factors should be measured and quantified to identify the optimum bougie for intubation procedures.

1.3 Focused Design Approach

Many designers fail due to a lack of focused approach during the design of everyday products. The design and testing phases are two of the most fundamental aspects to a focused design approach. Following a structured design methodology throughout the design process is extremely important and formulating a product design specification (PDS) and in some cases a component design specification (CDS) is a critical task. During the design of the SRTS, Pugh's Total Design Activity Model (Pugh, 1991) was considered. Predefining a design methodology mapped to the specification promotes an optimum total design activity, ensuring successful design and manufacture activities.

Designing an accurate SRTS will provide the authors with an opportunity to complete a detailed product review of existing bougies and future devices. By doing so, it is possible to conduct a complete market analysis that informs the anaesthesia community of optimum device selection. Ensuring a focused design and testing approach is utilised prior to the design of the testing system is imperative. Hodzovic et al., (2004a; 2004b) and Annamaneni et al., (2003) who evaluate various bougies, fail to consider several important factors within their testing equipment and setup that could influence data accuracy. Planning and utilising a focused design and testing approach ensures that variables that can affect accuracy of results can be both predicted and overcome. To improve validity of collected data in future studies, it is necessary to design new testing systems that accurately record and track various elements simultaneously. Siena et al., (2017), considers the following:

- Accuracy of equipment used to record data; i.e. considering maximum measurement ranges, load-cell capabilities and full-scale deflection accuracy (%FSD).
- Calibration and repeatability of standard testing parameters to allow the evaluation of equipment.
- Regulating/standardising the amount of pressure applied to shape the bougie.
- Repeatability of positional tracking of a bougie (analysis of bougie bend angle and orientation).
- Adaptability of the testing system ensuring accurate and statistically relevant testing data can be collected regardless of device brand.

2. SUMMATIVE SRTS PRODUCT DESIGN SPECIFICATION (PDS)

It is important to consider technology readiness levels (TRLs) during the planning and design of any new medical device or system. TRLs are a systematic metric/measurement system that allows the assessment of the maturity of technologies or concepts compared to the maturity between different types of technologies (Mankins, 1996). By implementing a design brief and a focused design approach in relation to TRLs, a detailed PDS can be generated.

Measuring technology and device maturity through TRLs, especially in the case of developing the SRTS, will allow new devices to be validated within the laboratory-based environment and progress through the TRL levels; this is most prevalent through TRL levels 4-6. This approach defines the key objectives and activities for the design process, thus ensuring a successful device or system can be produced. A summative PDS for the SRTS has been produced detailing the four key criteria and their detailed design requirements:

2.1 Performance

- Repeatable logic-based programming testing system utilising open access software (i.e. Arduino) with a protocol of pre-configured variables (i.e. actuators programmable for set movements). The system must provide a protocol of standard movements, reset protocols and adaptable parameters.
- Requires an accurate camera capable of recording and capturing the required data within the specified field of view (FOV) i.e. 3D Depth Camera. This must be connected to accurate camera/video tracking data acquisition software capable of recording at a fixed frame rate, within an appropriate field of view (FOV) thus allowing tracking of bend angles, tip movements, speed of movement and shape retention.

- Interchangeable angle measurement grids capable of recording different measures over clinically relevant ranges. The grids must be measured based on pixels to ensure calibration can be achieved.
- LED lighting system used to reduce the effects of ambient light to standardise the testing environment.
- Interchangeable components to standardised system setup regardless of the assessed equipment's diameter and length i.e. adaptable bend location points, adjustable grip chuck, adjustable bougie support beam, interchangeable linear actuator location points and motor bed location points.
- A quick speed, retractable bed, used to prevent bougie interference; lock points/brakes will also be required to prevent inaccuracies with data acquisition.
- Live real time object tracking (bougie movement mapping) and post processing assessment software is required to analyse bougie characteristics and suitability.

2.2 Installation

- The SRTS is required to be semi-permanent, however collapsible for transportation if required.
- Interchangeable grids are to be inserted into the designated slot; however, they must have a standardised origin and grid spacing to allow confirmation of calibration. Coloured grids may be required based on the variance of bougie colours.
- The lighting system must be installed to standardise the ambient light. This system should also aim to reduce the shadowing recorded on the interchangeable grids.
- The SRTS will require various power sources dependant on the equipment utilised; PC/Laptop (Mains Plug), Intel RealSense 3D Depth Camera (USB Powered), Linear Actuator (12V DC), Geared DC Motor (12V DC) and Brake System (5V DC Solenoid).

2.3 Testing

- Regulate and standardise the forces/pressures applied to shape the bougie. (This will vary based on bend location and distance from the bougie tip).
- The SRTS must be capable of conducting repeatable tests for several types of bougies/introducers yet still conform to standardised positional tracking.
- Accurately record and post-process the measurement of the bougie bend angle and orientation.
- The SRTS must be adaptable to allow the real-time data acquisition software to accurately map bougie movement and collect accurate and statistically relevant data regardless of the equipment assessed.
- Post processing software required to track data points and monitor bougie shaping and loss of shape to defining outputs including distance moved, angle variation, starting angle and speed.

2.4 Legislation

- The SRTS must be capable of producing quantifiable data that can inform the Difficult Airway Society (DAS) Guidelines and the DAS ADEPT Guidelines (Pandit et al., 2011).
- The system must be capable of contributing information to the DAS guidelines for management of unanticipated difficult intubation 2015, if data collected informs positive changes for best practice.
- The SRTS should conform to the testing requirements set out by the MHRA Medicines and Medical Device Regulations.

3. SRTS DESIGN & VALIDATION

The SRTS is a vision-based object tracking system that analyses the performance of difficult airway equipment utilising the Intel RealSense SR300 depth-sensing camera and a logic based repeatable testing system with pre-configured variables. The SRTS has been designed to function in three key stages; 1) SRTS control system uses the linear actuator pushers to manipulate the shape of the bougie; 2) The SRTS tracking system utilising object tracking (real time mapping) is activated and begins tracking the linear actuator pusher system (LAPS) then retracts allowing shape retention to be tracked; 3) Post processing data analysis software is utilised to analysedevice performance. An overview of the SRTS testing procedure and functions can be found in Figure 2.

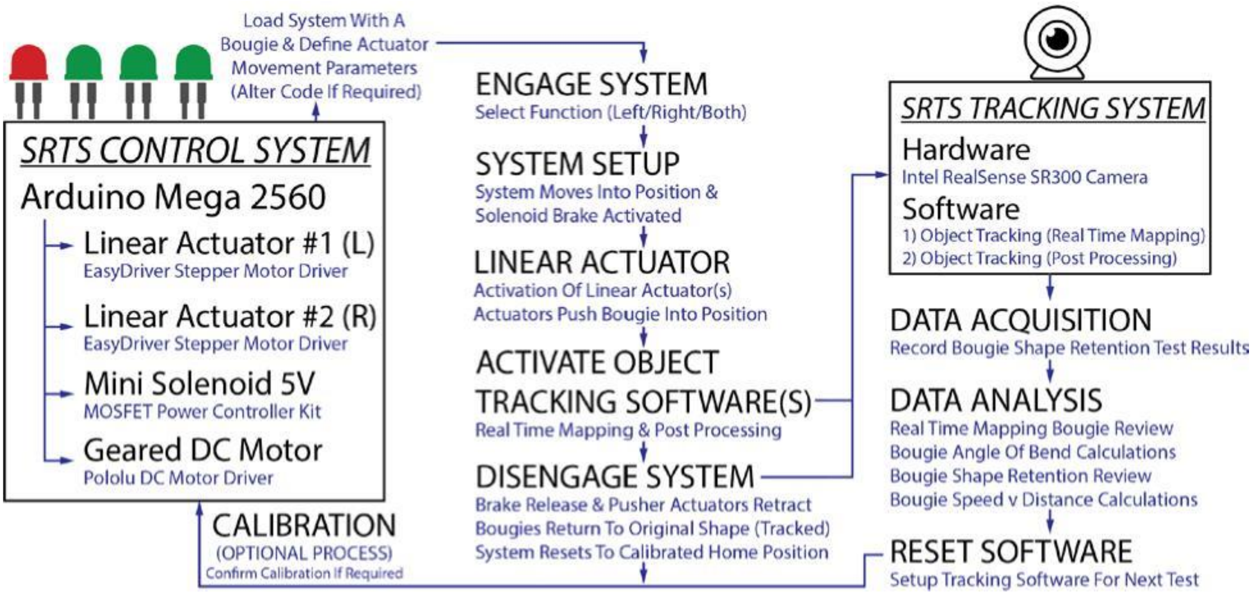

Figure 2. *Overview of Shape Retention Testing System (*SRTS)

3.1 Hardware

The SRTS (Figure 3) has many components that perform individual tasks. The LED lighting system creates a standardised lighting environment. The mechanical chuck grips the bougie and works in combination with the bend location piece, which defines the bougie bend point based on the distance from the bougie tip. The bougie support bar is used to prevent the bougie from falling onto the testing grid. The linear actuator pusher system (LAPS) is controlled by an Arduino Mega 2560 and utilises several motor drivers and power control modules.

Engaging the STRS utilising the power control box, the LAPS controlled by the geared DC motor moves forward until the front switch is pressed. Upon hitting the front switch, the operator then defines and activates the actuator(s) required to shape the bougie. After the completion of the programmed movements, the tracking software(s) are initiated. The disengage button is then pressed and the tracking software records the bougie movements; simultaneously the LAPS is retracting until hitting the back switch which immediately instructs the LAPS to reset to its calibrated home position. The SRTS utilises an Intel® RealSense™ SR300 depth camera. The SR300 is a short range, coded light 3D imaging system, combining depth sensing with a 1080p RGB camera that can be used for dynamic background segmentation, object tracking, 3D scanning, facial recognition, hand gesture recognition, amongst other applications. The SR300 is utilised in combination with the bougie angle measurement grid, real time mapping object tracking software and object tracking post-processing software to complete the desired tracking functions for the SRTS.

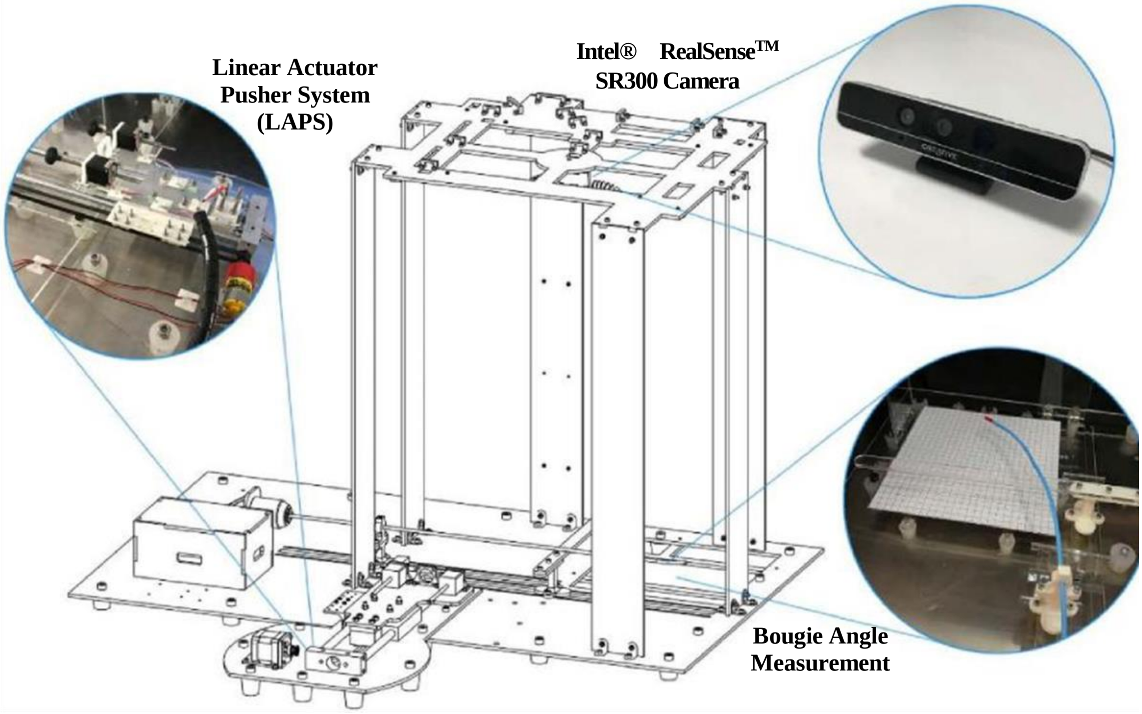

Figure 3. *Shape Retention Testing System (SRTS) Setup*

3.2 Software

The SRTS uses two software packages (shown in Figure 4 and 5) to complete an accurate assessment of bougies and their parameters. The Real Time Mapping Software (RTMS) utilises a live feed and object colour tracking to map the bougie tip movements; the Object Tracking Post Processing Software (OTPPS) however tracks the changes of shaping of the bougie whilst tracking the changes in angles, timings and distance. The RTMS identifies coloured objects and tracks their positional movement. When setting up the software, parameters need to be input; these include, selected camera feed, range, object height and width and defining objects colour (Figure 4, Left). Once setup correctly, the coloured object is tracked, and X and Y co-ordinate data is captured and plotted onto a position-tracking map as the object is moved (Figure 4, Right). The OTPPS tracks over a set number of frames and functions by tracking two points on the bougie, the origin/anchor location and the tip of the bougie. Data points are monitored and captured during bougie manipulation and as the bougie attempts to return to its original shape.

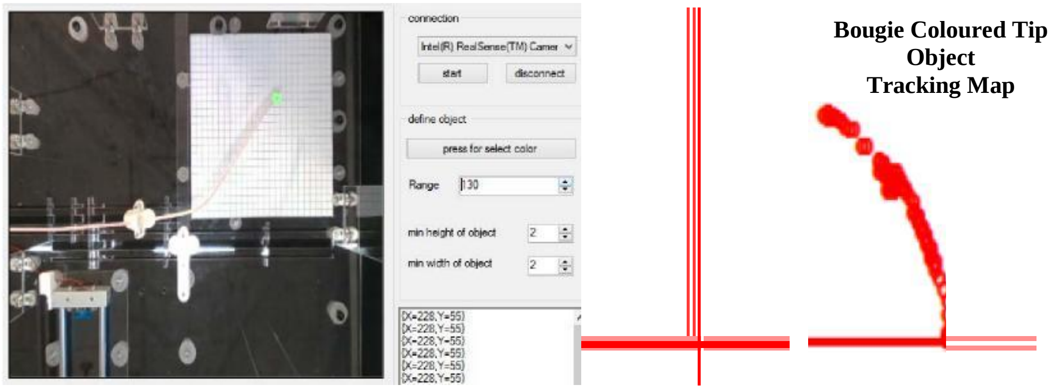

Figure 4. *Real Time Mapping Software - Tracking Live Feed (Left), Bougie Tip Tracking Map (Right)*

The video captured is then post processed and broken down into frame-by-frame images and analyses each image for the location of the anchor marker and the bougie tip marker. The tracked points are converted into X, Y coordinates based on the pixel location at the centre of each of the tracked markers. This is stored into an array with an item in the array for each frame of the video; this data is timestamped with a frame number and the number of frames per second in the video. Using this data array, we can now query the data to find out where the markers were at any given time in the video feed. Using trigonometry, the angle between the two points from each frame is defined. By subtracting one angle from the other, it is possible to calculate the difference between the two angles and establish how far the bougie has moved in the given time frame. Dividing this value by the time that has elapsed between the frames, the average speed that the bougie moved is calculated.

To avoid miscellaneous data points being tracked in the video stream, the software is setup to use regions of interest (ROI) for each marker. The ROI is the region on the SRTS that the software is instructed to search for markers; it will only seek the markers within the ROI and therefore avoids having the software track other similar items within the video feed that can distort the results. To achieve calibration and the correct scale, we must also calculate the number of pixels in the image per centimetre. This is achieved by placing a 1cm square grid under an observed area, the tracking software then finds the grid within each image and calculates the distance between the lines; the number of pixels residing between the lines provides us the scale in pixels per centimetre. Using this value, it is possible to calculate the distance between any two points within the image frame.

3.3 Validation

To validate the OTPPS, an initial bougie shape retention test was conducted. Figure 5 (Left) shows the bougie having been shaped into position by the LAPS and once released the bougies shape retention is tracked; the start and end points of this test can be seen in Figure 5 (Left). The video recorded is then post processed; once complete the OTPPS opens a dialog box with all the tracking data collected. The number of frames analysed (time-scale) can then be altered to calculate the required results.

In Figure 5 (Right), the frames analysed are set between 0 and 1000. Once calculated, a results dialog box appears stating the starting angle position (degrees), the distance moved (mm), angle variation (degrees) and the speed of the bougie movements (mm per second). In the test completed (Figure 5), the bougie was shaped to a starting angle of 121.2^{o}, the bougie then moved 149.27mm from the shaped position to the loss of shape retention position, the angle variation observed was 21.31^{o} and the speed of movement was 3.04 mmps.

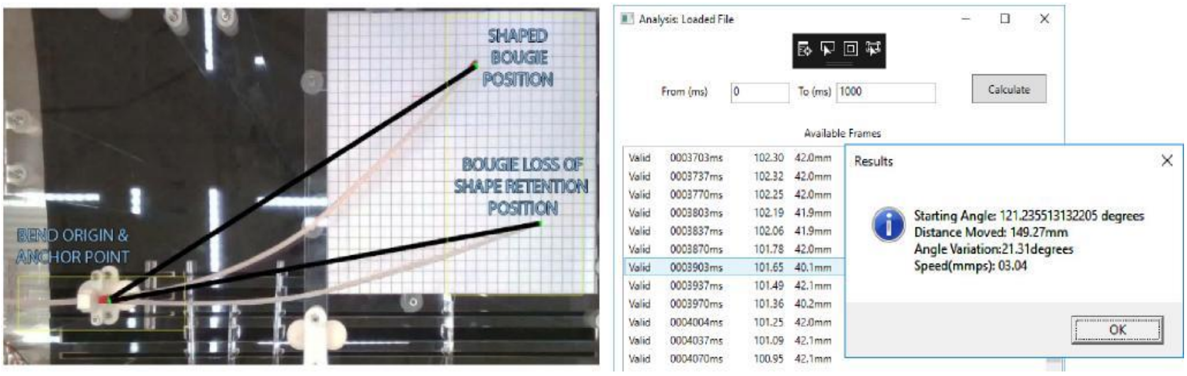

Figure 5. *Post Processing Software: Shape Retention Bougie Test – Start & End Position (Left), Data Acquisition & Results Screen (Right)*

4. CONCLUSIONS & FUTURE WORK

Developing the Shape Retention Testing System (SRTS) has generated a standardised, calibrated testing system, capable of providing quantifiable data. This can now help inform anaesthetists of comparative device performance, providing evidence for device selection and purchase and generating evidence for societies and academics to inform their guidelines for best practice. Utilising a focused design approach in combination with a product design specification and technology readiness levels, whilst considering the patient benefit and clinical need, this has enabled the SRTS to be manufactured, tested and validated. The initial testing has also proved that the desired measurables can be acquired utilising the data acquisition software and the post processing software, thus providing data that can be assessed for analytical review.

Based on the initial testing completed, the Object Tracking Post Processing Software (OTPPS) requires a few minor improvements including a calibrated region of interest (ROI) separate from the main grid to create an uninterrupted ROI for ultimate calibration. An adjustable colour input drop down list is required to define the colour of the tracking points that may change based on the variance in colour of different manufacturer's bougies. An adjustable ROI is also required for the anchor tracking point; these may vary based on the required bend location. Finally, a black out cover (i.e. dark room cover) will also be implemented. The next testing steps for the SRTS is to complete a full assessment of the most popular bougie introducers available on the market.

The Difficult Airway Society (2018) provides a comprehensive list of tracheal tube introducers, exchangers and guides; however not all of this equipment is compared in the studies conducted by Annamaneni et al., (2003), Hodzovic et al., (2004a), (2004b), Jackson et al., (2009), Janakiraman et al., (2009) and Marson et al., (2014). The ultimate objective is that the SRTS will be used to analyse the performance of the extensive bougie introducer range available for purchase to aid and identify the device(s) that provide optimum benefit with safe practice.

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State diagram for affective learning in an educational platform

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ABSTRACT

The impact of learner affect state in goal achievement and educational performance is discussed. Different learning theory models are explored and compared, a new combined state diagram for modelling learning challenge and skill level is adopted and expanded for the purpose of an adaptive learning platform. To accomplish this, a thorough understanding of affect state diagrams for learning and the relationship of affect, learner skill and learning material challenge is established. Optimal learning paths are explored and objective ways of tracking learner skill are and increasing learning challenge linearly is explained and demonstrated. To conclude, a proposal for an experimental study is presented to explore the impact that an adaptive affect conscious learning platform has on learning and learner engagement.

1. INTRODUCTION

There is now an accumulation of evidence to indicate the link between affect and cognitive performance and decision-making (Eysenck, Derakshan, Santos, & Calvo, 2007). The goal to learn and understand is associated with an increase in positive emotions like enjoyment of learning as well as a decrease in negative emotions like boredom. Affect can direct attention and influence the level of that attention. According to Thompson and McGill (Thompson & McGill, 2017), affect also functions as a motivator, influencing the tendency to approach or avoid a situation as well as how information is processed.

Student engagement (participation in learning) was found to be the most reliable feature for determining successful learning (Barry Carpenter et al., 2015; Iovannone, Dunlap, Huber, & Kincaid, 2003). Without engagement, deep learning is not possible (Hargreaves, 2006). Effective personalized learning was shown to encourage participation and engagement not only in the classroom but in extra-curricular activities and work related learning in the local community (Sebba, Brown, Steward, Galton, & James, 2007). As the tutor or the technological learning facilitator forms a better understanding of the learners' strengths and challenges, they are in a better position to go through scaffolding objectives, involving choice of skill to train at a given moment and choice of learning activities, while preserving the learners' interest and engagement (Dolan & Hall, 2001).

According to Carpenter (Carpenter, 2011) the process of engagement is a journey that connects learners and their environment (including people, ideas, materials and concepts) and enables learning and achievement. Students who are disengaged can become frustrated or bored, which can have a negative effect on achievement and lead to disruption of learning, for the individual learner, as well as for other learners when learning takes place in a collective/collaborative environment like a classroom.

The existence of the link between affect state and achievement suggests that a learning session may be improved if the teacher is sensitive and responsive to the emotional state of the learner (Goleman, 1995). However, the success of this strategy depends on the skill and experience of the human tutor and there is evidence to suggest that, especially with learners with special needs, teachers may find it particularly challenging to determine affect state (Vos et al., 2012). This was the motivation behind the MaTHiSiS (Managing Affective-learning THrough Intelligent atoms and Smart InteractionS) ("MaTHiSiS Project Website," n.d.), an educational platform developed as part of a H2020 project. MaTHiSiS aims to deliver personalized and adaptive learning to range of user groups. The MaTHiSiS system introduces two novel elements into the teaching situation: Smart Learning Atoms and an affective responsive delivery of learning materials.

Herein, we focus on the affect states identified as important by D'Mello, Picard (Mello, Picard, & Graesser, n.d.) who identified frustration, boredom and flow to be the most relevant emotions to skill acquisition. The concept of the Zone of Proximal Flow proposed by Basawapatna et al (Basawapatna, Repenning, Koh, & Nickerson, 2013) reflects these affect states in a two dimensional diagram of learner skill and learning challenge. Referencing independent learning limit and scaffolding from Vygotsky's Zone of Proximal Development (ZPD) with Csikszentmihalyi et. al.'s (Csíkszentmihályi, 2012) theory of flow. Carpenter (B. Carpenter, 2010) and Iovannone et al. (Blackburn, 2012) see engagement as the single best predictor of successful learning for children with intellectual disabilities. Capturing a range of raw data (e.g. eye gaze, body pose and movement, vocalisation), multimodal fusion, labelling, and inference related to learners' affect state allows us to model affect states from a wide range of types of learner from those with Profound and Multiple Learning Disabilities (PMLD) and autism through to adult learners on a career guidance course. In a separate paper (Burton et al., 2018) the use of multimodalities in tracking learner engagement has been explored. These concepts underlie the learning vision in providing an engaging learning environment in which learners with diverse needs and varying levels of ability are supported with assisted learning.

The relationship between affect state and learning achievement is crucial for the development for the affect based learning platform. This is the subject of this paper based on an examination of the literature and extension of Vygotsky's Zone of Proximal Development (ZPD) and Csikszentmihalyi's theory of flow. To this end we extend the work of other theorists who have already combined these two theories (Basawapatna et al., 2013).

The paper structure is as follows: Section 2 described the affect states for learning. Section 3, describes a linear approach to increasing learning challenge and delivers a formula for the objective calculation of learner skill in a linear learning task. Lastly, Section 4 explores the optimal pathway through an affective state learning diagram and proposes an experimental study to demonstrate the impact of the MaTHiSiS system, which incorporates an affective state diagram for learning.

2. AFFECTIVE STATES OF LEARNING

Affect states are defined as neurophysiological states best described as moods and emotion (Shernoff, Csikszentmihalyi, Schneider, & Shernoff, 2003). Some affect states relevant to learning include frustration, boredom, flow, eureka (Craig, Graesser, Sullins, & Gholson, 2004). Classroom-related affective states are linked to the students' goal structure and their adoption of specific achievement goal orientations. The goal to learn and understand is associated with an increase in positive emotions like enjoyment of learning as well as a decrease in negative emotions like boredom. Adopting a performance approach goal—that is, the goal to be better than others—was found to be associated with the positive emotions. In contrast, the adoption of a performance avoidance goal—that is, a goal not to appear incompetent, stupid, or uninformed in comparison to others— was related to a negative emotion like anxiety and hopelessness. However, the relation between goals and affect might not be a unidirectional but a reciprocal one as proposed in Linnenbrink and Pintrich's bidirectional model.

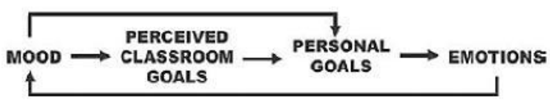

Figure 1: Linnenbrink and Pintrich's asymmetrical bidirectional model of achievement goals and affect.

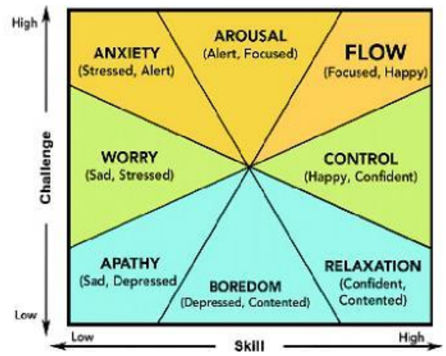

Figure 2: Csikszentmihalyi's theory of flow states[1]

In 2002, Linnenbrink and Pintrich described a model of affect in which goal achievement is reciprocally related to the learner's emotional state (Pekrun & Linnenbrink-Garcia, 2010). In this model (see **Figure 1**) the learners' personal goals are highly influenced by their perception of the learning activity challenge. This perception in turn has a direct influence on their affect state. Based on the wider literature, positive moods predict goal endorsement while negative moods predict avoidance goal endorsement.

[1] Frank Vandeven, accessed http://frankvandeven.com/getting-into-the-flow-what-does-that-mean/ on 7/3/2018

.

This relationship between skill and affect states has been more specifically described in Csikszentmihalyi's Theory of Flow (Mihalyi Csikszentmihalyi, 1996), where learner skill and their perception of the task challenge leads the learner to a variety of affect states, which he presented in **Figure 2**. Importantly, not all emotions are relevant to learning and parts of the theory of flow are less relevant to the scaffolding process in identifying optimal learning experience and moment where the learner requires scaffolding intervention. Sidney D'Mello and Rosalind Picard (Mello et al., n.d.) conducted a study on the relevance of emotions to learning and found Frustration, Boredom and Flow to be the most relevant emotions to skill acquisition. This has reduced the focus of the theory of flow to the most relevant and influential states of affect for learning.

In 1978, Vygotsky investigated the advancement of cognitive understanding by becoming interested in the process (L. Vygotsky, n.d.). The boundaries of learner skill were broken into segments, where learners have the capacity to learn independently, and assisted learning (instructional scaffolding) from a tutor or a more knowledgeable peer, the later called the 'Zone of Proximal Development'.

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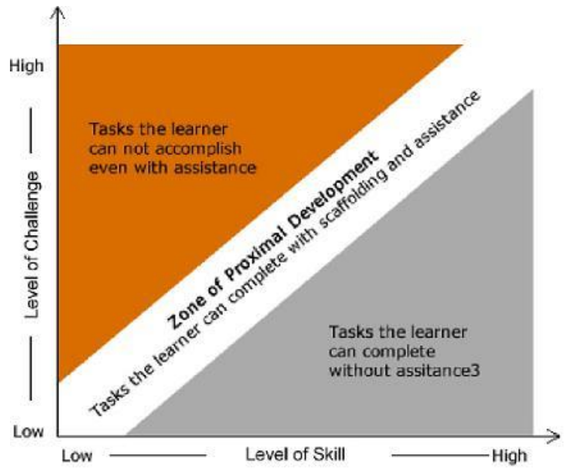

Figure 3: Morsink's graphical representation of The Zone of Proximal Development[2]

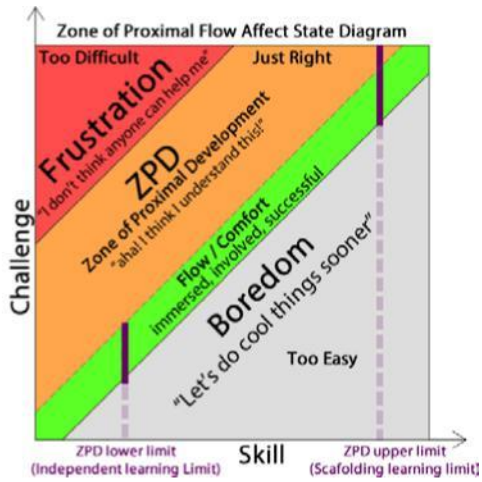

Figure 4: State diagram from the Zone of Proximal Flow theory adapted from Basawapatna et al (Basawapatna et al., 2013) to include both the ZPD lower independent and upper scaffolding learning limits

Only later, in 2013, was it that Basawapatna et al. (Basawapatna et al., 2013) combined learner skill, independent learning limit and scaffolding in the 'Zones of Proximal Flow' (ZPF) state change diagram. Critically this work provided the first state change diagram to reference both Vygotsky's ZPD and the affect states from Csikszentmihalyi's theory of flow. Moreover, to adapt this diagram to facilitate an educational platform, knowing the imitations of the individual learning is important in designating when the platform should mediate and deliver scaffolding intervention. To this aim, the ZPD limit to independent learning from Vygotsky's theory has been applied to the ZPF diagram and we introduce **Figure 3** as the more complete affect state diagram for learning. The learner's skill level is displayed as the X-Axis and the task challenge is displayed as the Y- Axis. Unlike Csikszentmihalyi's flow diagram, or Vygotsky's ZPD, a single ZPF graph can be used to track the learner's progress in a learning activity and any permutations of level of skill or task difficulty.

A learning experience with a learning platform comprises interactions with the learning material, the 'challenge' of an activity, as depicted in the diagram of **Figure 3** and will consist of learning material with different levels of difficulty. The maximum level of difficulty observed by an external expert judge is use as a baseline for the highest level of challenge in the graph. In this way, the graph can plot more than one learner. Two ballet students learning the same ballet move could be plotted on the same ZPF graph - but importantly setting a global not relative ground truth allows the system to influence the user's movements in the graph with only one independent variable, 'challenge'. The ground truth is set against tangible measures that can be tested (by the expert or the indicators the expert sets the system to monitor) and in this monitoring is achieved through performance analytics (correct and incorrect responses and response time measures) and affect state tracking.

2 Paul Morsink, *TILE-SIG Feature: The "Digitally Enhanced" Zone of Proximal Development*, http://literacyworldwide.org/blog/literacy-daily/2013/09/20/tile-sig-feature-the-digitally-enhanced-zone-of-proximal-development, accessed on 7/3/2018

To evaluate the learner accuracy and success, completion time (e.g. learning achievement completion time, time taken to answer a question) is tracked alongside the learning material challenge level in order to determine learner performance in relationship with activity challenge, affect state and learner skill level.

2.1 Frustration

According to Zone of Proximal Development theory, Frustration is where the learner cannot achieve new learning even with assistance. Studies have found that actors who perceive that they lack the skills to take on effectively the challenges presented by the activity in which they are participating experience frustration. Simply put, if a learner feels incompetent in a given situation, he or she will tend not be motivated (Mihaly Csikszentmihalyi, Nakamura, & Abuhamdeh, 2005). This is a negative experience and its gravity pulls the learner further into frustration, in a deteriorating cycle that hampers the learning process. In this state, the learner is exposed to a hopeless feeling; his or her emotional state could be represented by the statement "I do not think anyone can help me".

2.2 Vygotsky Zone of Proximal Development

The ZPD refers to 'the state of arousal where the learner can perform an action or skill provided the aid of a skilled or knowledgeable tutor or in collaboration with more capable peers'(L. S. Vygotsky & Vygotskiĭ, 1978). This achievement is limited by the ZPD upper limit, however this limit is dependent on the skill of the 'more knowledgeable peer' or scaffolding tools, better tools achieve better results as do more knowledgeable peers induce and encourage higher levels of skill achievement on others due to their access to higher levels of knowledge. This zone limit has been illustrated in **Figure 4**, with the vertical line. While in this zone, the student with assistance can acquire higher skill (Chaiklin, 2003; Radford, Bosanquet, Webster, & Blatchford, 2015; Read, 2006; Verenikina, 2003). In this zone, the level of challenge provides the optimal arousal and engaging experience for the learner to obtain new skills. In this state, the most engaging learning experiences for the learner can happen; it is where optimal and deep learning opportunities manifest themselves. According to (Hermida, 2015) "deep learning is a committed approach to learning. It is a process of constructing and interpreting new knowledge in light of prior cognitive structures and experiences, which can be applied in new, unfamiliar contexts". Deep learning results in better quality learning and profound understanding. While in this zone the student with the assistance of the tutor (instructional scaffolding or assisted learning) acquires higher skill and is encouraged to learn and mentally develop (Chaiklin, 2003; Radford et al., 2015; Read, 2006; Verenikina, 2003).

2.3 Mihaly Csikszentmihalyi Flow

Csikszentmihalyi first described flow in 1997 (Shernoff et al., 2003) as the state where the learners are fully immersed, feeling involved and successful. Flow is a delicate state where the skill level and task challenge levels are balanced. This state represents the learner state where the learner is functioning within their independent capacity, i.e. where the learners find themselves in their comfort zone, both in terms of the learning challenge or learning styles. Flow is also the state where new learning materializes as a new skill in the mind of the learner, which provides the learner an opportunity for reinforcement learning, that carries a successful emotional feeling.

Skill advancement in flow however is limited by the learner's lower limit of ZPD (the maximum a learner can achieve independently) which has been shown with a vertical line in **Figure 4**. Therefore, in order for the learner to achieve new learning outside their independent capacity, the learner must eventually leave flow and be lead to ZPD, to pursue new learning opportunities (i.e. acquire a new skill or to complete competence of partially acquired skill). In either case, in flow or while in ZPD the learner is limited to the upper level of ZPD, which is dependent on the scaffolding tools and scaffolder.

2.4 Boredom

Boredom is the state where the learner is not challenged sufficiently. This state can manifest through the addition of a dry skill base through lecture style teaching, or by providing interactive activities that do not challenge the learner outside what they have already learned. Boredom is a negative feeling and its gravity pulls the learner further into this state, leading to learner disengagement and stifling the learning progress. In this state, the learner's emotional state could be represented by the statement: "let's do interesting things sooner".

In boredom, the low level of challenge relative to skill allows attention to drift. Particularly in contexts of extrinsic motivation, attention shifts to the self and its shortcomings, creating a self-consciousness that impedes engagement of the challenges. Goetz and Hall review development of learners' boredom, and call it an emotion that is frequently experienced by students and can undermine their learning and performance (Robertson, 2015).

3. LEARNING CHALLENGE AND LEARNER SKILL

Learning challenge is a measure for the skill required to complete an activity. Consequently, the unit of learning challenge is the same as skill. When visualized in a graph (see **Figure 5**), any challenge above the diagonal of the graph would represent an increased difficulty and anything underneath the diagonal would represent a lower difficulty. Difficulty does not necessarily match one for one with the user's perceived difficulty of the task, but it is a simple way of representing a tasks challenge relative to others with variable difficulty levels.

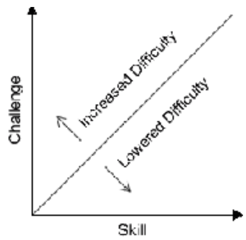

Figure 5: Learning material difficulty vs learner Skill

3.1 A linear approach calculating learning challenge

Learning action difficulty can be changed by adding more steps to the workload (see **Equation 1** which demonstrates this for a mathematics addition problem) or by adding more complexity (see **Equation 2** which demonstrates more difficulty achieved by replacing single digit addition with double digit addition)

$$x + y \text{ can become } x + y + z \qquad \textbf{Equation 1}$$

$$x + y \text{ can become } xy + wz \qquad \textbf{Equation 2}$$

Adding more steps or complexity also translates to different subjects. For example, in Geography, difficulty increase is made possible by enumerating the question with more answer combinations. This requires more processing before the correct answer is discovered.

Which country is in Africa? *[Difficulty 1]*
a) Lesotho b) Ecuador c) Guyana d) Trinidad and Tobago
Can become:

Which three countries are in Africa? *[Difficulty 3]*

a) Lesotho, Togo, Djibouti

b) Ecuador, Surinam, Eritrea

c) Guyana, Burundi, Mauritania

d) Trinidad and Tobago, Morocco, Togo

These are simple examples on how to achieve a simple linear progression in question and answer difficulty– however, in a more complex procedural skill acquisition task, the number of steps required to complete the task could represent the level of difficulty and this can be translated to almost any type of activity. For example, the number of steps in solving a physics problem, playing a musical score, performing a specific ballet move.

3.2 Calculating Learner skill

To quantify learner skill, a learner's response accuracy percentage (correct to total available attempts) for each level of difficulty towards the greater encompassing skill will be recorded not as a percentage but a value towards the completion of the learning activity. In this way, 100% accuracy of a learning activity difficulty is awarded 100 points, and 90% accuracy is looked on as 90 points, and so on. The sum of these points is divided by the total levels of overall skill difficulty (in this example 10 levels) becomes the average skill of the learner for that skill (see **Figure 6**).

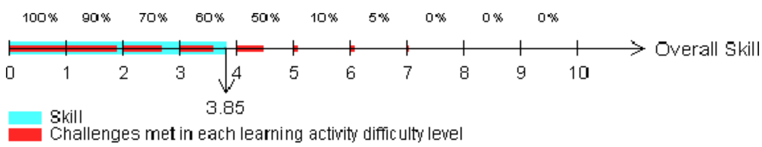

Figure 6: Learner skill calculation in a learning subject with 10 different levels of difficulty

4. LEARNER ENGAGEMENT THROUGH ADAPTIVE LEARNING

Supporting learner engagement is important for deep learning and skill achievement. Students who are not engaged can become frustrated or bored which can have a negative effect on achievement and lead to disruption in the classroom, which influences the learning of others. Importantly, many learning processes depend on a simple 'text' for the transfer of knowledge and evaluation. A single mode of learning can have limitations. For example, for a dyslexic student that has a reading-related learning disability, the single source of information transfer therefore becomes a problem (Dolan & Hall, 2001). Universal Design for Learning recognizes this problem (Rose & Meyer, 2001) by embracing the pupil learning diversity by offering multiple means of learning accessibility. Multi-media learning platforms can use audio, audio text, video and tangible objects in a smart learning environment to offer the student a choice of the most accessible formats. This allows for multiple means of recognition, expression and engagement (Dolan & Hall, 2001; Rose & Meyer, 2001). Multi-media approaches in learning resources are best demonstrated in the use of computer-mediated learning where educational games are developed around the learning outcomes and aims. This approach, which is not new, was shown in a systematic review of 129 papers by Connelly et al. (Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012) that playing educational games impacts across a range of areas including engagement, cognitive ability and, most commonly, knowledge acquisition and content understanding.

4.1 Optimal learner experience reflected through Zone of Proximal Flow state transitions

How do we apply affect knowledge to a learning platform? Guided by the affect state and the ZPF state diagram of a learner the appropriate level of learning material challenge in order to maintain the learner in an optimal condition where both engagement, as well as skill achievement is maximised can be determined. 'Flow' and 'ZPD arousal' learning states are the active learning states of the learner. New skill acquisition and skill uptake maximisation happens in ZPD, while maintaining the learner in the state of flow and provides the opportunity for reinforcement learning (as visualized in **Figure 7**) which can solidify skills acquired during the learning process and enhance the learning experience itself. Although new skill is not acquired in flow, a slow parallel growth over the long term, with the increase of the level of challenge, introduces an increase in learner skill. This is however limited to the to the lower ZPD independent learning limit, and to increase skill further beyond that, the learner must enter the ZPD.

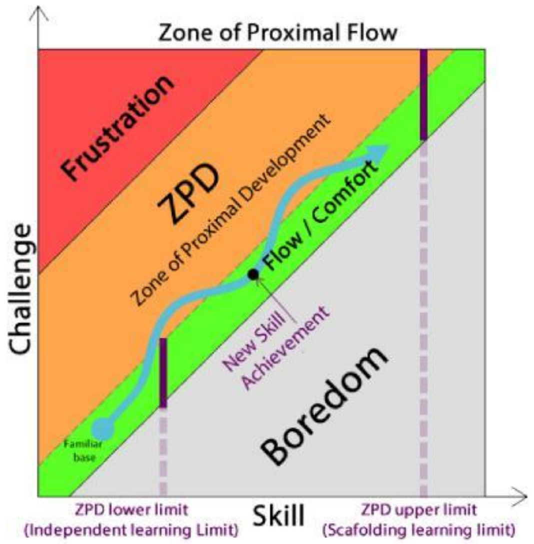

Figure 7: Optimal learning experience loop in ZPF diagram adapted from Basawapatna et al (Basawapatna et al., 2013).

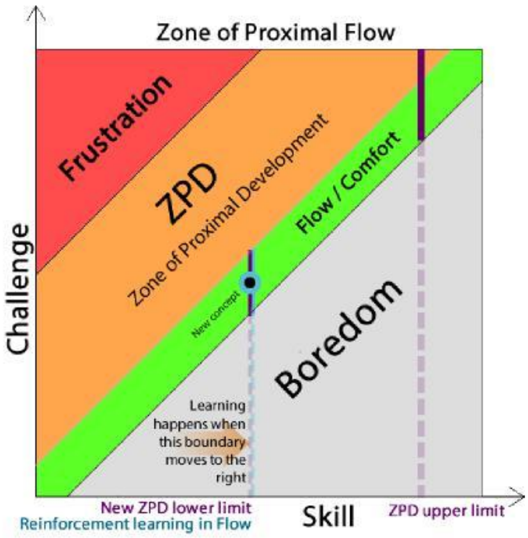

Figure 8: State change is paused while reinforcement learning takes place adapted from Basawapatna et al (Basawapatna et al., 2013). The ZPD lower limit is moved to reflect the new skill achievement.

Any learning material difficulty adaptation processes needs to maintain the learner in the optimal path, as portrayed in **Figure 7**. The optimal path is the one with the shortest forecasted achievement time and one that facilitates the most positive affect states. This path must take the learner through arousal and avoid boredom or frustration. It should start at the lower limit of the ZPD (familiar base) to avoid unnecessary repetition while allowing the learner to remain in the state of flow to enable reinforcement of acquired knowledge (reinforcement learning) visualized in visualized in **Figure 8.** This loop of leaving flow and entering the ZPD (shown as a snakelike pattern in **Figure 7**) should continue until the maximum possible skill achievement is obtained (highlighted by the upper ZPD limit). The caveat being that the 'familiar base' (starting concept) should be challenged for specific learners with disability to re-evaluate previously established learning outcomes.

This process is a delicate one, when the learner is in flow, a continuous effort to push the learner out of their comfort zone and into the ZPD zone by challenging them to greater levels of difficulty will stimulate the learner.

However, if the learner is projected too far into arousal, the learner becomes frustrated. By monitoring the learner affect state and learner skill level, a learner can will oscillate between the ZPD and the state of flow with new skill materialization. As a result, a new concept materializes as the learner's skill with just-in-time principles as displayed in **Figure 8** as a circle in the green area. Adaptive learning requires continuous monitoring of learner affective state and Learning Activity progress. The learning path is far more engaging and optimal and the learner is always in a positive affective state. Maintaining the learner in the state of flow provides the opportunity for reinforcement learning.

4.2 Proposed experimental *study*

In this paper, we have proposed how affect state model can be employed to maximize engagement and therefore learning outcome. We plan to raise two research questions; first, what is the relationship between affect state and learning? Second, what impact does an active affect state guided learning platform have on learning and engagement?

The first research question we will investigate by correlating indicators of progress through learning materials with affect- based sensor data (e.g. eye gaze, body pose and movement, vocalisation) extracted from MaTHiSiS educational platform.

The second research question we will use a within subjects ABAB design. Each participant acts as their own control undergoing a series of sessions, some of which are the intervention (A–with the MaTHiSiS system where affect information drives progression through learning materials) and some of which are the control condition (B–the MaTHiSiS system where affect information does not drive the progression through the learning materials). This approach is taken because while reusable learning objects have been widely investigated, MaTHiSiS is the first to introduce an affect state driven response to the learning material presentation. With that in mind, the evaluation is designed to compare the addition of the affective element.

5. CONCLUSION

A literature review has been carried out to form the theoretical background for coupling learning to the emotional state of the learner. The wider literature shows that there is a strong relationship between learning goal outcome achievement and a learner's affect state. Positive affect state have been shown to encourage greater learner outcomes and sustained engagement leads to deep learning and long-term skill retention. The zone of proximal development and the theory of flow's usefulness in explaining the learning process of an educational platform has been described. The Zone of Proximal Flow (ZPF) state diagram is expanded to include the lower ZPD limit and its usefulness as a state diagram for the platform is explored. ZPF affective states in the educational platform have been defined and each affect states importance and impact on individualised learning through the platform has been compared.

A methodology for measuring relative task challenge for a learning activity has been proposed. Methods for linear progression in learning challenge have been developed and examples have been provided. An objective learner skill progression calculation methodology for a wide range of activities is proposed and examples demonstrated. Optimal learning pathways in an educational platform have been described using the ZPD state diagram, and methods for sustaining learner engagement are proposed. To conclude, using the ZPD affect state diagram, methods have been proposed to calculate learner skill and learning activity challenge—in order to locate the learner's affect state and location on the ZPD graph and in turn offer the best intervention for sustained learner engagement. Sustained learner engagement has been shown to be the most reliable identifier for deep learning and retained knowledge.

An experimental design to investigate the impact of this approach system which incorporates the affect state diagram for learning is proposed. This will help us to understand the relationship between learning and affect state and the impact of the system on learning and engagement.

ACKNOWLEDGMENTS

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Strengthening social-emotional skills for individuals with developmental disabilities through virtual reality games

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ABSTRACT

Defining qualities of developmental disabilities include deficits in social-emotional skills, especially with respect to emotion recognition. The present study aims to assist adults with developmental disabilities in strengthening emotion recognition skills through the research of available technologies and the development of a virtual reality (VR) game, EmotionVR. The study explores existing methods that enhance emotion recognition, evaluates the HTC Vive as a feasible VR system for the game, observes user interactions with the HTC Vive and virtual environments, and analyses users' interactions with EmotionVR over the course of two iterations. In the first iteration of EmotionVR, two stages were included to assist with learning facial expressions and applying the learned knowledge in naturalistic settings. Data produced from the first iteration suggested that users would benefit from reinforcement of learned facial expressions. The second iteration of the game consisted of three stages, where users were given the opportunity to reinforce what they learned. Users enjoyed VR as a mode of learning social-emotional skills, and found the experience more realistic. The findings of the study suggest that teaching social-emotional skills through the use of immersive and interactive VR systems is an effective method of learning these skills.

1. INTRODUCTION

Developmental disabilities, such as Autism Spectrum Disorder or Down Syndrome, affect 17% of children born in the United States (CDC, 2015). They are often characterized by deficits in social-emotional skills, including difficulty recognizing emotion through facial expressions (Pochon & Declercq, 2014; Cebula et al., 2017). The ability to effectively recognize emotions through facial expressions is crucial to enhancing emotional competence, of which developing strong interpersonal skills relies on. Without strong interpersonal skills, adults with developmental disabilities struggle with obtaining a job, maintaining personal relationships, and advancing academically or professionally.

1.1 Issues with Traditional Methods of Therapy to Teach Social-emotional Skills

Adults with developmental disabilities will often seek assistance with learning social-emotional skills from behavioral and/or speech therapists. Therapists provide training on emotion recognition and effective methods of emotional expression, utilizing tools that include flashcards, iPad applications, and videos. These therapies can cost between $46,000 and $47,500 a year, under the premise that the individual has undergone similar therapies as a child (Lindgren & Doobay, 2011). Individuals without health insurance, or with plans that do not cover these therapies will find themselves unable to access the care that they need at such a high cost. Accessibility of such resources is also variable depending on the availability of highly trained therapists in the region that these individuals live in.

1.2 Previous Work Regarding Virtual Reality for Individuals with Developmental Disabilities

It has been suggested that virtual reality environments have been beneficial to individuals with developmental disabilities, such as Autism. This is due to the ability to control factors and components during virtual simulations and game play, create safe learning environments, and allow for the use of technologies that these individuals find intriguing and engaging (Anderson, 2017; Strickland 1998). Researchers have also explored virtual reality as a mode of occupational therapy for individuals with Down Syndrome, who found traditional methods of therapy repetitive and uninteresting (Wuang et al., 2010). Through the use of VRWii gaming technology, these researchers were able to effectively increase participant's motor skills, while also providing a motivating and entertaining experience.

2. OVERVIEW

This work aims to critically examine existing methods of aiding individuals with developmental disabilities in learning social-emotional skills through the development of a virtual reality game. It was important to accomplish the following tasks to ensure an enjoyable and effective experience: 1) gain an understanding of the methods and techniques employed by a behavioral and/or speech therapist to enhance emotion recognition skills; 2) evaluate the usability of the chosen virtual reality system; 3) observe and analyze user interactions with the chosen system and the virtual environment; and 4) analyze findings and translate them into a virtual reality game.

2.1 Understanding Traditional Therapy Methods

Hope Services, a local community center for adults with developmental disabilities, agreed to assist with the study by providing access to a speech therapist responsible for teaching members of the organization how to strengthen their social-emotional skills. The community center served as a meeting place where interviews with the speech therapist took place. Two interviews with the speech therapist took place. The purpose of the first interview was to understand the role of the speech therapist at the community center, and how she organized therapy sessions with members of the organization. The second interview served as an introduction to the types of tools the speech therapist used to teach social-emotional skills.

During the first interview, the speech therapist gave an overview of the types of clients she works with and outlined how often she sees them. Her client base consists of adults who have difficulty with fluid speech and who are non-verbal. She stated that it was uncommon for her to meet with a client who had never worked with any type of speech or behavioral therapist before. The speech therapist visits Hope Services once a week, but mentioned meeting with each client only once or twice a month. She stated that she should prefer to see each client at least once or twice a week to consistently help them learn necessary skills, but because of the amount of clients at the organization, she is often unable to see clients more frequently.

For the second interview, the speech therapist brought tools she commonly uses during therapy sessions to teach social-emotional skills. These included an iPad, workbooks, and flashcards. She focuses on trying to teach emotion recognition through facial expression during her sessions with members from Hope Services. She stated that her clients enjoy using the iPad, especially since the games used during sessions are meant to be entertaining. The games she uses consist of facial expression matching games and scenario based games where users guess how a character feels in a given situation. The characters in the games were cartoonish, and had exaggerated facial expressions. The workbooks and flashcards consist of facial expression matching, and exercises where users will be asked to identify emotions of people in photographs. The facial expressions present in the workbooks and flashcards were either cartoons or images of real people.

From these two interviews, it is understood that users have a preference for technology. It is also suggested that while users have access to technology during sessions, they are limited to the interactions they can have with virtual characters or tools. The interview also pointed out that beyond interactions with the speech therapists, individuals also have limitations on realistic facial expressions that they are able to practice emotion recognition on.

2.2 Evaluation of the HTC Vive

The virtual reality system chosen was the HTC Vive. This was the system of choice because it allowed for users to interact with the virtual environment with their left and right hand through respective controllers, and provided an immersive virtual reality experience through the headset.

The evaluation of the HTC Vive was conducted with 8 students, 4 of which were male identifying and 4 of which were female identifying. The mean age of these participants was 21 years. Participants were asked about their previous experiences with virtual reality systems prior to starting the evaluation, and all users responded that they had never used one before the evaluation.

Users were asked to play a game on the HTC Vive, and were interviewed on their experience using the system. When asked to rate the comfort of the HTC Vive on a Likert Scale from 1 to 7, where 1 was not comfortable and 7 was very comfortable, the average rating was 5.125. When asked to rate the usability of the HTC Vive with respect to ease of use of controls and playing the game on a Likert Scale from 1 to 7, where 1 was not intuitive at all and 7 was very intuitive, the average rating was 6. Users' overall experience using the HTC Vive was positive and without difficulty, as reflected in their ratings of the comfort and usability of the system.

2.3 User Interactions with the HTC Vive and Virtual Environment

To gain an understanding of the users' interactions with the HTC Vive and virtual environment, 4 members of Hope Services were invited to play a game on the HTC Vive. These members consisted of 4 males between the ages of 25 and 37, with varying developmental and physical disabilities. While playing the game, we observed the users' interactions with the virtual environment and their use of the HTC Vive. Users played with a virtual rollercoaster simulator and a star catching game.

After playing both games, users were asked about their thoughts about the games and using the HTC Vive. All participants had a positive experience with the games played on the HTC Vive, and would want to play a game on the system again. Half of the participants enjoyed the rollercoaster simulator over the star catching game, while the other half enjoyed the star catching game over the rollercoaster simulator. Of those that preferred the rollercoaster simulator, they mentioned favoring the feeling of being in an actual rollercoaster, and the more natural setting that the game took place in. Those who preferred the star catching game liked that the game allowed them to interact with the virtual environment in a format that they were familiar with.

With respect to using the HTC Vive, none of the users showed any displays of discomfort or motion sickness, and did not mention any feelings of discomfort or motion sickness when asked. Users were able to easily use the controls and push the buttons necessary to play the game. Users were then asked about their general video game preferences and experiences. All users have had experience playing video games on consoles such as the Xbox 360 and Nintendo Wii. Games that users mentioned playing on these consoles included Assassin's Creed, Grand Theft Auto V, and MarioKart.

2.4 Designing the Game

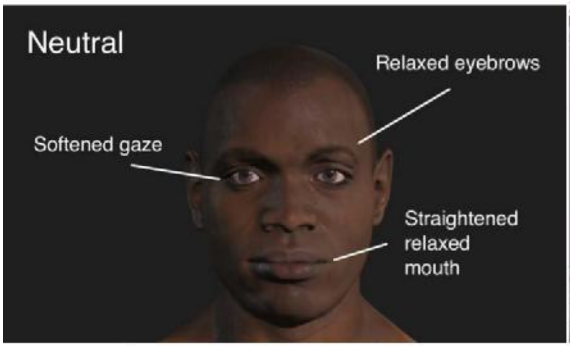
Data collected from interviews with the speech therapist, evaluation of the HTC Vive, and user interactions with the HTC Vive contributed to the design of the game produced through this work. Through the interview with the speech therapist, we found that users were comfortable identifying emotions through facial expressions when given a still image of the facial expression. With respect to evaluations and user interactions with the HTC Vive, it was important to allow for user interactions with the virtual environment, and to make the virtual environment realistic. It was also notable that for safety and reasons of inclusion, users should be either sitting or have a limited range of which they could physically move around in the virtual environment. This was due to variability in users' physical abilities during the user interactions with the HTC Vive.

2.4.1 Game Development Tools

The game was developed for the HTC Vive using Unity as the main game development platform. Virtual characters were created and animated using Adobe Fuse and Mixamo. Background art was created through the use of Adobe Blender and the Unity Asset Store.

2.4.2 Theme and Game Layout

The game was designed with an overarching detective theme, where users would be trained as a new detective under the supervision of a lead detective, Olivia. Users would be expected to learn how to recognize 5 emotional facial expressions in a training room with Olivia, and then go to a scene where they would attempt to identify these facial expressions in a natural setting. The 5 emotional facial expressions provided were: happy, sad, angry, surprised, and neutral.



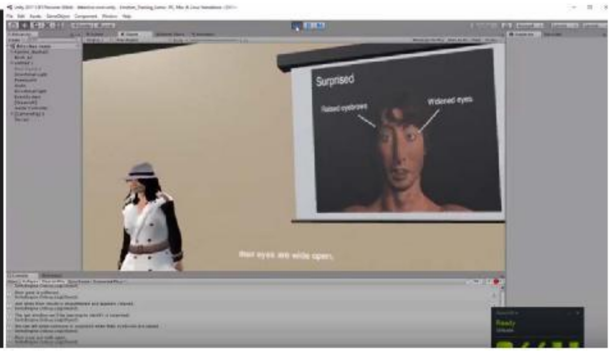


Figure 1.*View of Training Room* **Figure 2**.*Neutral Training Slide*

Upon starting the game users would enter a training room, where slides of each of the emotions are projected on a screen. The slides, shown in Figure 2, would detail what emotion was being presented, and what specific facial features you could use to identify such emotion. The facial features were individually labelled, and the user would be given the option to repeat slides if they felt it necessary. Once users finished reviewing the slides, they would be sent to a park, where a party was on going. There would be multiple characters displaying different facial features in the park, and Olivia would ask the user to find someone displaying a specific emotion. The user would then select the character displaying this emotion, and narrate why they chose this specific character.

2.4.3 Baseline Emotion Data

To gain an understanding of users' current levels of emotion recognition skills, we conducted an emotion recognition assessment. The assessment consisted of both images and video scenarios, where a specific emotional facial expression is being displayed. There were 10 photos consisting of emotional facial expressions, and 5 videos consisting of scenarios where individuals would react a certain way and display specific emotional facial expressions. There were 10 members of Hope Services with developmental disabilities of varying degree who took the assessment. These members have undergone behavioral and/or speech therapy focused on assisting with learning social-emotional skills in the past. On average, they were able to identify the emotions present in the images and videos 62% of the time.

3. USER TESTING: ITERATION 1

The game was tested by 9 individuals from Hope Services between the ages of 21 and 54. Of these individuals, 2 identified as female and 7 identified as male. Prior to participating in the study, users were briefed on the consent form outlining study objectives, anticipated risks, and consent for video and audio recording. They signed the consent form if they felt comfortable participating.

The first part of the game contained the training room, where users were taught how to identify the following emotions through specific facial features: sad, angry, happy, surprise, and neutral. Users were shown PowerPoint slides detailing what the specific features looked like, along with labels for each facial feature and respective emotion. Users were given the option at the end of each set of slides for a particular emotion, to repeat the respective slides if they felt the need to. Once users went through all the emotions, they would be brought to the park scene.

In the park scene, users were asked to identify someone displaying a specific emotion. For example, users would be asked to, “Find someone who is happy”. There were 10 characters in the park, each displaying a different emotion. For each of the 5 emotions taught in the training room, there were 2 characters in the park expressing the emotion. Users would select characters by pressing a button on the HTC Vive remote, thus displaying a laser pointer in the virtual environment. Users would point the laser at the character they believe displays the emotion in questions, and justify why they chose this character verbally. Once users finished this portion of the game, they were praised for completing the game and asked to complete a questionnaire about their experience.

The questionnaire used for the first iteration contained 15 questions, 8 of which were based on a Likert Scale. The scale’s parameters were from 1 to 5, where 1 was the least and 5 was the most. These questions asked users how they felt about the game’s general aesthetic, characters, game instructions, and how confident users felt before and after playing the game.

4. RESULTS: ITERATION 1

Users were scored based on the number of emotions they were able to identify correctly during the park scene. On average, users were able to identify 49% of emotions correctly while playing the game. Per emotion, 4 out of 9 participants were able to recognize happy, 5 out of 9 participants were able to recognize surprised, 3 out of 9 participants were able to recognize sad, 4 out of 9 participants were able to recognize angry, and 2 out of 9 participants were able to recognize neutral. In comparison to the baseline assessment, users were able to recognize 13% less emotions than they did in the assessment.

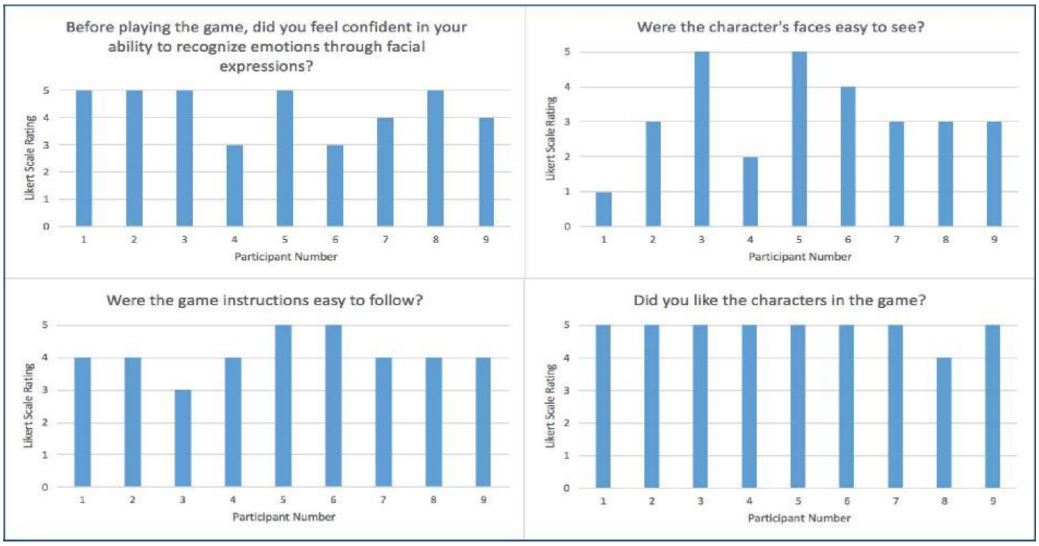


Figure 3: *The responses to specific Likert Scale questions are detailed above. A rating of 1 corresponds to more negative feelings, such as “did not like at all” or “not easy to follow”. A rating of 5 corresponds to a more positive feeling, such as “really easy to see” or “really confident”.*

The questionnaire users responded to after playing the game consisted of 15 questions, concerning the comfort of using the HTC Vive, clarity of graphics, and experience playing the game. The results from the questionnaire show that 33% of participants mentioned that the headset was uncomfortable while playing the game. With respect to graphics clarity, 23% of participants mentioned difficulty with viewing character’s faces, making them out to be too grainy or small to see specific facial features. When asked about the ease of recognizing character emotions, 67% rated them easy to identify, while the remainder said that they were either hard to recognize or neither hard nor easy to identify.

Participants were asked to rate their ability to clearly view character faces on a Likert Scale ranging from 1 to 5, where 1 represented great difficulty viewing character faces and 5 represented great ease when viewing character faces. Data shows that 67% of participants rated the difficulty of viewing character faces a 3 or below. When asked to rate their confidence in ability to recognize emotion prior to playing the game, all participants rated their confidence as a 3 or above, expressing an average to great amount of confidence in their abilities. Of these individuals, 56% rated their confidence as a 5. In considering if the game made participants feel more confident in their abilities to recognize emotion, all participants responded that it did.

With respect to open ended questions, users recalled enjoying the game and the game aesthetics. In particular, users enjoyed the scenery present in the park scene along with the clothing of the characters. Users mentioned learning more about specific emotions during the training room scene, but also recall learning social-emotional skills not specifically taught in the training room. For example, users described their strategies in trying to determine what emotion a particular character was expressing, which included making eye contact with the characters. Users would have preferred more interactions with the virtual environment to make the game more interesting, and would have preferred that the game give them more practice learning the emotions.

Data from observations of the participants playing the game show that only 33% of participants utilized the feature allowing them to replay slides going over how to recognize specific emotions through facial features. Upon starting the game, users generally needed assistance with using the HTC Vive controls, but once they were shown how to progress the game, they were able to independently continue the game and use the controls. Users were also shown to have some confusion while in the park scene level of the game, when they were asked to justify choosing a character that is displaying a specific emotion. Users responded by giving examples or scenarios as to why the character might be displaying a specific emotion, such as "they are sad because their friend could not make it to the party". We sought an answer with respect to facial features that detailed why a character was expressing a specific emotion, so participants were asked to follow up their reasoning with specific facial features.

5. DEVELOPMENT OF GAME: ITERATION 2

Data from user testing with the initial iteration of the game suggests that users will benefit from rearrangement of the characters and environment, along with a reinforcement stage included in the game. Of the users who participated in the testing of the first iteration of the game, 67% rated the ease of viewing character faces as a 3 or below on a Likert Scale from 1 to 5, where 1 was difficult to view and 5 was easy to view. In qualitative data analysis, it is suggested that users would benefit from the opportunity to spend more time learning the information, as some users were completely unfamiliar with emotions, such as neutral, as recognizable facial expressions.

Researchers developed the reinforcement stage of the game to feature a corkboard, as an extension of the training room. To allow for more interaction with the virtual environment, as well as provide a means of practice in recognizing facial expressions, we created a corkboard featuring images of characters with the 5 different facial features that the users learned in the training room slides. The images would move towards the user's view, as Olivia asks them to identify what emotion the person on the image is expressing. The user is asked to vocalize their answer and to give reasons why they believe the facial expression illustrates the emotion they gave as an answer. The image then flips over to reveal the facial expression image, labelled with the respective emotion and labels to facial features that tell the user how to identify this emotion.

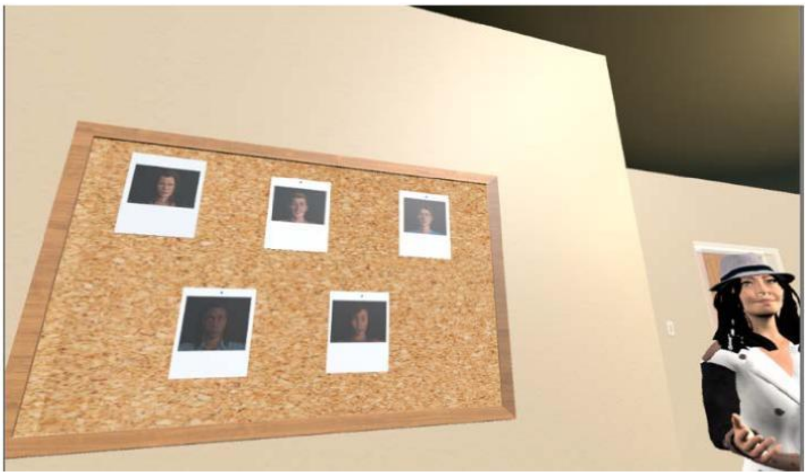


Figure 4: *The corkboard displays 5 photographs, each with a different emotional facial expression.*

Once users finish identifying the facial expressions on the corkboard, they are then brought to the park scene. The park scene is the third stage of the game, where users are asked to identify characters displaying a specific emotion. Changes were made from the first iteration of the game in this stage to include more characters, and to have the characters surround the user. In doing this, we were able to provide a view of the characters' facial expressions more clearly to the users, as well as include more characters to choose from. The virtual environment was also edited to include more objects one would find in a park, such as pathways and benches, to make the environment seem more realistic. Users are asked to identify characters who are displaying a specific emotion, and to select this character with the remote. Their selections are recorded through Unity and saved into a text file.

Figure 5: *The characters are arranged around the user's view, symbolized by the white outline of a cube. This allows users to be able to look around and have a clearer view of the characters' facial expressions.*

6. USER TESTING: ITERATION 2

The game was played by 16 individuals from Hope Services between the ages of 22 and 59. Of these participants 8 identified as female while the other 8 identified as male. Of these users, 13 had mentioned using the HTC Vive prior to this study. Data from 2 users were deemed unusable in the study, since they consisted of users who were uncomfortable with using the HTC Vive or who were unable to verbally communicate with researchers concerning their answer choices. Prior to participating in the study, users were briefed on the consent form outlining study objectives, anticipated risks, and consent for video and audio recording. They signed the consent form if they felt comfortable participating.

Users were asked to play through the game, similar to the first iteration, except this time the game play included the reinforcement stage. Users entered the game in the training room, being shown slides on how to recognize 5 emotions through facial expressions, with each facial feature labelled. These emotions included: happy, sad, angry, surprised, and neutral. Once users finished going through the slides, they were brought to the corkboard, and asked to identify the facial features on the pictures. They were asked to verbally give and explain their answers. Upon completion of this stage, users then moved on to the park scene, where their knowledge was tested. Users were asked to select characters who displayed specific emotions, and their scores were collected and saved into a text file. Users were then asked to complete a post questionnaire about their experiences with the game.

This second iteration of the questionnaire consisted of 17 questions, 8 of which utilized a Likert scale to give quantifiable user feedback about the game aesthetic, instructions, and previous game experience, similar to the first iteration. Additionally, user comfort, perceived game difficulty, perceived learning, and enjoyment were considered. The remaining questions consisted of demographic information and open ended questions for qualitative information on user experience.

7. RESULTS: ITERATION 2

Users were scored similarly as in iteration 1 of the game, with respect to obtaining points for correct answers. In the second iteration of the game, the corkboard and park scene were individually scored.

In the corkboard scene, users on average were able to identify 3.06 out of 5 emotions right, making them correct 61% of the time. Of users, 5 were able to correctly identify all of the emotions presented to them on the corkboard, while 1 user was unable to correctly identify any of the emotions presented to them.

In the park scene, the average score was 3.125 out of 5, which means users were correct 63% of the time. Of users, 2 correctly identified all of the emotions. These users also correctly identified all of the emotions in the corkboard portion of the game.

With respect to the post questionnaire, users were asked about how much they learned from the game, how enjoyable they thought the game was, and how comfortable the headset was. On average, users rated the amount that they learned a 3 on a Likert Scale from 1 to 5, where 1 meant that the user did not feel like they learned anything and 5 meant that they felt like they learned a lot. The average rating for enjoyment of the game and for the comfort of the game were both 4 on a Likert Scale from 1 to 5, where 1 was not enjoyable or not comfortable at all and 5 was very enjoyable or very comfortable. 81% of users mentioned that they would be willing to play the game again.

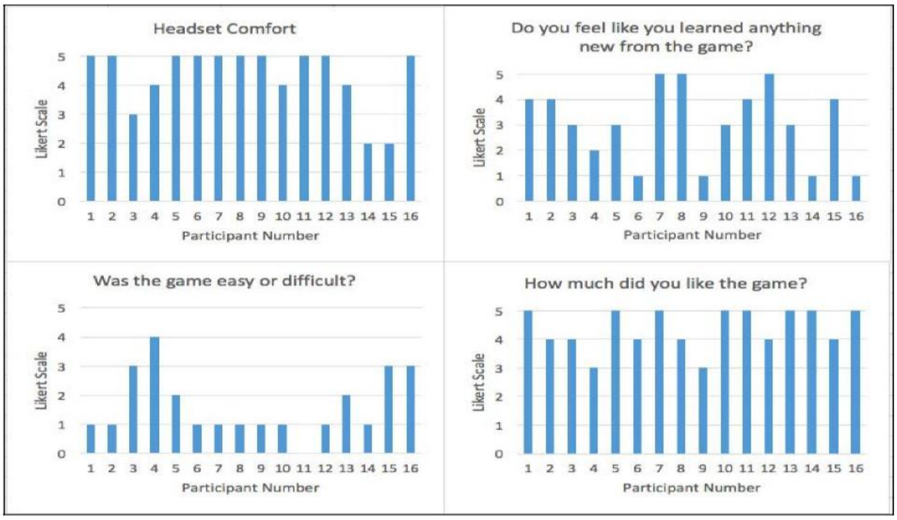


Figure 6: *Responses to specific Likert Scale questions from the second iteration of the game testing. 1 corresponds to a low rating, such as "Did not like at all" or "Extremely uncomfortable headset" while a 5 corresponds to "Really liked the game" or "Very comfortable headset".*

8. DISCUSSION AND CONCLUSION

The goal of this study was to understand if virtual reality was a feasible mode of assisting individuals with developmental disabilities in strengthening social-emotional skills. The baseline data for correctly identified emotions was 62%. With respect to the first iteration of the game, there was a difference of -13%. Reasons for this difference may be outlined in the survey asking users about their game play experience. In a question concerning users' ability to easily view character faces in the park scene, 67% of users rated the ability to view the faces a 3 or below on a Likert Scale from 1 to 5, where 1 was difficult to view and 5 was easy to view. Users also vocalized that discomfort while wearing the headset prevented them from being able to fully immerse themselves in the game.

Changes made to the second iteration of the game, including the reinforcement stage, have allowed for the average scores to rise and be closer to the baseline data. In the reinforcement stage, users were able to provide the correct answer 61% of the time, and in the testing stage, users were able to select the correct character 63% of the time. The differences between the first and second iteration of the game in comparison to the baseline data suggests that the addition of the reinforcement game increased the ability of users to correctly identify emotion through facial expressions. It also suggests that with the inclusion of a reinforcement game along with clearer views of character facial expressions, that virtual reality games are a feasible medium for use in teaching social-emotional skills to individuals with developmental disabilities.

While the second iteration of the game produces data closer to the baseline data, there are still discrepancies in the data between the reinforcement stage and testing stage. In comparing the data of participants in these stages, 50% of participants saw a decrease in number of emotions correctly recognized between the reinforcement stage and the testing stage. The remaining saw either an increase or no difference between the number of emotions correctly identified between the two stages. This may be explained by difficulty with transferring learned knowledge between different contexts, where users are able to correctly identify emotional facial expressions in one context, but have difficulty completing the same task in a different context.

Users in the first iteration of the game voiced much concern about the discomfort of the headset and the inability of view characters' facial expressions. In the second iteration of the game, users found the headset much more comfortable, even though the system had not changed. There were still some difficulties with headset discomfort for some participants, where one participant was unable to wear the headset comfortably because it was too big for their head even when adjusted. One user did not want to participate in the study due to their previous experience with discomfort using the headset. Users did not voice as much difficulty viewing character faces as was mentioned in the first iteration of the game, suggesting the rearrangement of the characters allowed for better viewing.

Consistently through both iterations of the game, users were entertained and felt like they learned something. They also consistently enjoyed the design of the environment and the characters and would play the game again.

For future researchers interested in this field of work, they may want to take care in finding a virtual reality system that their users will consistently find comfortable and user friendly. They may also want to focus more on providing exercises on transfer of social-emotional skills, such as practicing recognizing emotional facial expressions in different contexts.

Based on the results of this study, the use of virtual reality games for providing assistance for individuals with developmental disabilities in strengthening social-emotional skills, such as emotion recognition is feasible. Provided that the games are played utilizing a virtual reality system that is comfortable and has clear, high quality graphics, and that the users are given a chance to reinforce what they have learned before testing their skills, virtual reality games may be able to provide users with a more entertaining and motivating mode of strengthening social-emotional skills.

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Obesity prevention platform for the promotion of healthy eating habits and physical activity.

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ABSTRACT

Research efforts have successfully produced the development of prevention programs that have been effective and profitable. In Mexico, the problem of childhood obesity is on the rise, and there is a need of joint national efforts to prevent this problem. Our university has developed the web site "1, 2, 3 for me!" aimed at children from 8 to 12 years of age, their parents and teachers. The contents were developed for the teaching of healthy eating habits and the promotion of physical activity. Initial results will be presented in relation to the evaluation of usability and impact of use.

1. INTRODUCTION

The World Health Organization (2017) reports that the number of children with obesity in the world has increased tenfold in the last 40 years and, if current conditions are maintained, by 2022 there will be more obese than malnourished children.

In Mexico, 3 out of 10 children between 5 and 11 years of age are overweight or obese, and there is a progressive increase in the combined prevalence of excess weight and obesity in rural areas in both sexes. (ENSANUT, MC. 2016)

The prevention and treatment of obesity is complex and multidisciplinary, involving various aspects, both medical and psychological. In psychology, an important aim is to increase motivation, promote changes in lifestyle and foster healthy habits that prevent weight gain. In the case of childhood obesity, this is even more important since an adequate intervention in the first stages of development prevents chronicity in the adult.

Our laboratory at the National Autonomous University of Mexico, with the support of the García Río Arronte Foundation joined the national efforts in this socially relevant problem, developing the website "¡1, 2, 3 for me!", aimed at children between the ages of 8 and 12, their parents and teachers. The website was published on April 30, 2018, presented during a press conference and disseminated through various media outlets.

2. WEB SITE FOR CHILDHOOD OBESITY PREVENTION

The website offers various technological resources which were designed based on models of universal prevention for childhood obesity with reported effectiveness and efficiency, to contribute to the important task of reducing this health problem in our country.

Named "1, 2, 3 for me!, this website is an online resource that allows free access and downloads, enabling the Mexican population to obtain expert information on the problem of obesity and the habits for its prevention. The contents of the website were developed with an interactive approach in order to teach healthy eating habits and promote physical activity; users have access to all resources at any time and place using a mobile device.

The interactive activities of the website emphasize the importance of decision-making and encourage users to develop skills and strategies to maintain a healthy weight in a fun and interactive context, rather than in isolation or with faulty information and repetitive exercises.

Figure 1. *As part of the interactive space theme, navigation through the site is done through a menu with buttons in the shape of planets.*

Serious video games encourage girls and boys to explore the possibilities and limits of weight control and how entertainment can be considered a source of fun information for maintaining health. They share the characteristics of being attractive and amusing, with the objective of teaching basic information on nutrition, such as the differentiation of food groups, as well as the measurement of food portions recommended for maintaining a healthy nutrition.

Figure 2. *Avatar for the presentation of the "1, 2, 3 for me!" website.*

Usability evaluations of the platform and its contents will be presented, as well as the initial results of the acceptance of the platform by the target population.

3. METHOD

3.1 Main objective.
To scale and evaluate the digital web page "1,2,3 POR MI", for the promotion of healthy eating habits and physical activities, targeted to children (around 8 and 12 years old), to be used via internet, with the goal of promoting self-control and bonding to the program, adjusting to the characteristics and demands of the population targeted, and establish this program on schools and healthcare centers, specialized on the assistance of child population.

3.2 Specific objectives.

- *To scale and evaluate the impact of the Childhood obesity prevention program "1,2,3 POR MI" to promote healthy eating habits, as well as physical activities, aimed for boys and girls (around 8 and 12 years old).*
- *Evaluate the efficiency and effectiveness of the web page "1,2,3 POR MI", to promote healthy eating habits, as well as physical activities, aimed for boys and girls (around 8 and 12 years old).*

3.3 Stated hypothesis.

- *It's expected that the program will be effective for rising physical activity.*
- *It's expected that the program will be more effective in the long-term maintenance of the achieved goals on eating fruits, vegetables, hyper caloric food and physical activities.*

- *It's expected that the program will be accepted and appreciated by users (children, families and teachers) as well as not having difficulties when being implemented.*

3.4 Participants

1200 children, from 8 to 12 years old, will be recruited from 12 primary schools of México, with the authorization from the school and the informed consent from the parents.

3.5 Study Design

To evaluate the impact, effectiveness and efficiency of the obesity prevention program, the Solomon four groups design was selected. The participants will be assigned to one of the four groups that includes the research design. Groups 1 and 3 will receive the prevention program through the website "¡1, 2, 3 por mí!, assisted by an expert and technical support; only group 1 will have pre-test evaluation; Groups 2 and 4 will receive the prevention program in a traditional way, but only group two will have a pre-test evaluation. During the Post-test evaluation, a series of questionnaires will be applied to gather information on the usability of the website in order to know the acceptance of the users to whom it is addressed.

Parallel to the evaluation, tools such as Google Analytics will be used to analyse the behaviour of users within the website. With this information you can have an indicator of the people benefited and the strongest aspects of the program, or that are more popular for our population; besides having a direct means of identifying the elements that must be adjusted.

3.6 Usability evaluation

During the website development and its contents some usability evaluations will be performed, with the objective of knowing the webpages acceptance from the targeted public, as well as how easy it was to use and navigate inside it. As a part of the evaluation, physiological response measurement was included, a bio-feedback system that allows to know if there is any physiological change while using the website contents.

3.7 Analysis of results

The results will be analysed in the next three dimensions:

- Regarding the impact, it will be the personalized reports derived from the use of the Google Analytics tool, which will allow us to obtain information about the impact of the program and the relationship that users establish with the website; more specifically, the information of the sections and services most visited will be an indicator of the use of the website. By analysing this behavior, you can effectively guide the effort to strengthen the points of interest of the site, as well as a change of strategy in the presentation of the sections suffer from a lag in the interest of users.
- In relation to the analysis of effectiveness and efficiency, data will be processed according to the experimental design, we will perform Pearson's or Spearman's correlation test according to the distribution of the variables to know the correlation between the RA and the score of the scales of IE and of CAR. A value of $p < 0.05$ will be considered significant. The comparison between the students of the different schools will be made by student's t test for continuous variables according to their distribution and comparison test for the nominal and ordinal variables.

To check mediators and moderators that confirm the constructs of the theoretical model documented as effective, we will evaluate the constructs derived from this model in the Mexican population. We will apply a multiple regression analysis with the scores of the evaluations by built-in construct.

4. EXPECTED BENEFITS

Currently, technological resources allow us to disseminate these advances with the latest marker of success in universal prevention strategies, the large-scale impact on public health in our country. A noteworthy aspect is that information and communication technologies take advantage of the relationship between cost and effectiveness. A program with these characteristics represents less cost in time and money, considering that a physical space with particular characteristics is not needed. At the same time, it allows reaching a large number of people, breaking the social and geographical barriers.

The use of the Internet and information technologies will reduce the associated costs of the implementation of this type of prevention programs, directing preventive information through the means that this segment of the population (children between the ages of 8 and 12), use at this stage of their life.

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Caregiver involvement makes the difference between repetitive behaviours and engaged learning in a computer-assisted therapy for autism

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ABSTRACT

Point OutWords™ (http://www.PointOutWords.online/) is a free, open-source, iPad-assisted, caregiver-delivered therapy that aims to develop manual motor skills for communication in people with autism who lack functional communicative speech. This pilot study delivered a two-week trial of Point OutWords to five nonverbal / minimally verbal autistic children (two girls, three boys, ages 9-14) in special education, assessing acceptability of the caregiver-delivered format in a school setting. The Social Responsiveness Scale – 2 and the Parenting Stress Index – 4 were applied as test-retest measures. Whereas one student's parents were actively involved in supporting and reinforcing the delivery of Point OutWords at home, constraints on school staff time meant that the other four essentially were left alone with the iPad. One of these four dropped out of the study, and the other three showed no change on the external test-retest measures and a worsening on measures of efficiency of motor execution internal to the Point OutWords software (duration and path length of targeted dragging movements, spatial error of pointing movements), suggesting that the software was being used as a vehicle for repetitive behaviours rather than a vehicle for learning. In contrast, the student who was using Point OutWords in the prescribed, caregiver-delivered format improved on internal measures of motor efficiency and on the social subscale of the parent-reported SRS-2. Within this small, school-based sample, potential therapeutic effects of Point OutWords appear to depend on the availability of caregiver support in the delivery of Point OutWords.

1. INTRODUCTION

1.1. Communication deficits in ASD

Communication deficits are a key symptom in the diagnosis of Autism Spectrum Disorders (ASD). These impairments in communication can refer to an individual's understanding of language (e.g. receptive skills) and how they provide information (e.g. expressive skills). Each individual can vary in ability in terms of these deficits, ranging from no verbal communication to highly idiosyncratic language. 25 to 30 percent of people diagnosed with ASD are nonverbal or minimally verbal (Koegel et al., 2009; Anderson et al., 2007; Lord et al., 2004). These high percentages highlight the importance of exploring communication in nonverbal individuals diagnosed with ASD. Impairment in communication skills can have troublesome implications for individuals with ASD in later life, affecting social functioning and academic attainment (Venter et al., 1992) and some cognitive abilities (Fernell et al., 2013), and negatively impacting adaptive behaviours such as daily living skills and some social skills (Park et al., 2012). However, over recent years it has been noted that there is a lack of research exploring these nonverbal children (Kasari and Smith, 2013) and more specifically research exploring possible reasons and interventions for these communication deficits in nonverbal individuals.

1.2. Motor control and communication in ASD

Recently we identified a subtype of nonverbal / minimally verbal autism in which receptive outpaces expressive language, and this receptive-expressive disparity correlates with deficits in motor and particularly oral motor skills (Belmonte et al., 2013). A research review conducted by McCleery et al. (2013) found that deficits in motor control are likely to negatively affect social communication and language development in individuals diagnosed with ASD. This developmental relationship is supported by research suggesting that delays in motor skills, particularly in the first two years of life (Bhat et al., 2012), may predict communication deficits in individuals with ASD, suggesting that early motor skills appear to set the stage for the development of communication skills. Bishop (2002) examined 79 sets of twins diagnosed with ASD, finding a strong association between oral motor and manual motor skills. Together, these findings suggest that deficits in motor control may aggravate social communication and speech language skills deficits in individuals with ASD.

1.3. Autism Interventions

Although the literature presents significant support for a relationship between motor control and communication deficits in ASD, this relationship is rarely exploited in regards to possible interventions. Research is also missing regarding effectiveness of interventions for nonverbal individuals. A number of interventions are available for nonverbal ASD, the two most popular of these being Sign Language Training (SLT) and the Picture Exchange Communication System (PECS).

PECS is used to establish communication within social contexts in individuals with ASD. In a meta-analysis of 50 studies, Sulzer-Azaroff et al. (2009) found that PECS can be effective for communication development in ASD. However, the subjects in most of these studies had some previous verbal communicative skills. Therefore, it is not yet clear whether PECS is an effective intervention for communication deficits in nonverbal individuals with ASD specifically.

Sign Language Training is used to facilitate speech and communication development in individuals diagnosed with ASD. However, nonverbal individuals with ASD tend not to develop any form of communication through SLT (Schlosser and Wendt, 2008; Layton and Watson., 1995). It should also be considered that the complex motor ability to form manual signs is essential for the use of SLT as a communicative tool. A recent meta-analysis found that motor coordination deficits are pervasive across the diagnosis of ASD (Fournier et al., 2010), suggesting that many individuals diagnosed with ASD might not have the motor skills required for SLT. As a result, such motor-impaired individuals are excluded from the effectiveness of such interventions.

1.4. Point OutWords

A relatively new phenomenon in autism intervention research is the use of tablet- and computer-based software. Such methods have become popular due to their obtainability, affordability and customisability (Shane et al., 2012). A recent systematic review (Lorah et al., 2015) examined 17 studies evaluating the use of handheld computing devices for development of communicative skills in ASD. Compared to traditional techniques such as sign language, the preference of subjects in most studies was a tablet-based intervention. Point OutWords is one such method. Point OutWords (Belmonte et al., 2016) is free iPad software designed with and for autistic users, targeting communication development specifically through motor control training. The current study focusses on the transition from Point Mode, in which users assemble jigsaw puzzles of everyday objects by pointing and dragging puzzle pieces iconically, to Type Mode in which users must type the sequence of letters in the object's name to assemble the puzzle symbolically.

2. METHODS

The study used a within-subjects experimental design. Five children (two females, three males) aged between 9 – 14 (mean 12.4, SD 2.07) were recruited from a special school in Nottingham, UK. Clinical ASD diagnosis was confirmed by the parents/teachers of the participants. Informed consent was obtained from parents/guardians, and informed assent was obtained from the children. Subjects used Point OutWords for a two-week intervention period and were asked to aim for 30-minute sessions, occurring at least 5 days a week, either at school during school hours and/or at home depending on the preferred location. The Social Responsiveness Scale – 2 (SRS-2) and the child domain of the Parenting Stress Index – 4 (PSI-4) were administered at the beginning and end of the intervention period. Linear regression models were used to analyse movement statistics.

For each movement across the touchscreen, the path efficiency statistic (Path per Distance in Table 1) refers to the ratio of the actual distanced travelled by the finger across the touchscreen to the shortest possible distance from the starting point to the ending point. The time efficiency statistic (Duration per Distance in Table 1) refers to the ratio of the actual time taken for the movement to the direct distance covered by the movement. The spatial error statistic is the distance between the point of initial contact on the touchscreen and the nearest edge of the puzzle piece nearest that point of contact. All units of space (display pixels) and time (machine clock ticks) are arbitrary. In addition, variance of scalar speed and circular variance of angular heading during drag movements were computed within each individual movement, as measures of consistency of motor execution parameters over small amounts of time during movement execution, and then regressed over contact time with Point OutWords.

At the end of the intervention period, Point OutWords was assessed via verbal feedback from the subject's parents and teachers. They were asked for feedback on the individual engagement of each subject, any negative or positive comments on Point OutWords and any suggestions for future improvements.

3. RESULTS

PSI-4 scores were identical pre- and post-intervention. For the SRS-2, T-score profiles were calculated for the three subjects for whom complete data were available both pre- and post-intervention. Two subjects (#2 and #5) showed no change on any subscale (including awareness, cognition, communication, motivation and mannerisms). Subject #1's scores decreased (i.e. improved) on the communication subscale and the mannerisms subscale, and increased on the awareness subscale.

Logged data from the Point OutWords software for four subjects were examined. Subject #4 provided no useful data as only a few puzzles were presented and no touchscreen contacts were logged for them. Data from the other three subjects were included in the analysis. Linear regression models were used to analyse movement statistics (discussed above and see Table 1), where movements are indexed from the user's first interaction until the user's final interaction. Thus a negative regression slope would suggest that the movement function in question were decreasing with practice, meaning that the subject's paths were becoming shorter, times becoming faster and spatial errors lessening.

Table 1. *Inferential statistics of time efficiency, path efficiency, and spatial errors*

	Duration per Distance				Spatial Error					
	F	df_{denom}	p	Slope	F	p	Regressi on Slope	F	P	Regression Slope
1	16.90	658	**<0.000 1**	**-0.00842**	10.63	**0.0012**	**-0.0007299 1**	11.03	**0.0009**	**-0.03813**
2	9.13	677	0.0026	+0.02197	14.75	<0.0001	+0.00108	5.24	0.0224	+0.01615
3	3.98	3316	0.0460	+0.00040427	2.78	n.s.	n.s.	36.88	<0.0001	+0.00074807
5	0.49	1033	n.s.	n.s.	5.96	0.0148	+0.00096065	21.02	<0.0001	+0.03139

Whereas subjects #2, #3 and #5 worsened on these measures of motor efficiency, subject #1 improved. The analysis of movement variance tells a similar story: Subject #1 showed no change in variance of speed or circular variance of heading. Subject #2 showed increased speed variance ($F(1,677) = 26.92$), $p < 0.0001$) and no change in heading variance. Subject #3 showed increased speed variance ($F(1,3316) = 208.92$, $p < 0.0001$) and increased heading variance ($F(1,3316) = 32.88$, $p < 0.0001$). Subject #5 showed increased heading variance ($F(1,1033) = 8.02$, $p = 0.0047$).

In qualitative feedback, subject #1's parents reported that he very much engaged with the software for about an hour at a time. Subjects #2 and #5 engaged for long periods at the start of the intervention but began to dismiss the iPad as time went on. #3 enjoyed engaging with the iPad for the first week and a half but became bored over the final few days and figured out how to close the app. Teachers found it difficult to sit with each individual subjects for extended periods as they had other children in a class to focus on also.

4. CONCLUSION

Qualitative feedback provides key context to the quantitative data: Subject #1 showed improvements across subdomains on the SRS-2 and on the internal motor measures, and was the only subject using Point OutWords as a joint activity with a caregiver. Although subjects #2, #3 and #5 all worsened across motor measures, the deterioration in #3 was not as pronounced as in #2 and #5. This finding is corroborated by the qualitative feedback in which it is reported that #3 only started to dismiss the iPad in the last few days, compared to #2 and #5 who started to dismiss the iPad after the first week.

Lone usage is expressly not how Point OutWords is meant to be applied. The software was designed to work with parents and teachers rather than substituting for them (Belmonte et al., 2016) and the results of this study- though only suggestive given the small sample and lack of randomisation- seem to give backing to this instruction. The only subject (#1) to show improvements, across multiple measures, was the subject whose parents were involved, whereas those subjects whose movements became less efficient were those who used the software alone. This result is consistent with thematic meta-analysis highlighting involvement of therapists or parents as an active ingredient in interactive computer-based therapies for neuromotor developmental disorders (Levac et al., 2012). It remains unclear and a subject for further qualitative and quantitative investigations what characteristics may have determined #1's substantive engagement with Point OutWords, and conversely #4's lack of engagement. These findings therefore suggest- though cannot establish, as only one subject used the software at home with a parent- that in the absence of joint interaction between user, caregiver, and technology, the technology may be co-opted as an outlet for repetitive behaviour, and that communicative therapies designed to incorporate caregiver involvement may be unlikely to generalise to real-world communication unless this involvement comprises real, purposive social communication either integrated into the therapy or surrounding it.

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User involvement in virtual reality treatment groups

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ABSTRACT

Non-attendance of treatment groups in the community has been a long-standing problem. Using virtual reality to deliver remote group therapy may improve attendance. Two focus groups were held with mental health patients and carers to conduct user involvement. Recommendations were given on the study design, recruitment criteria and recruitment strategies.

1. INTRODUCTION

Treatment groups for psychiatric patients are routinely provided in community settings, in a variety of treatment modalities and for different diagnostic groups. Because of their cost-effectiveness and therapeutic advantages, they are recommended as a treatment for different groups of psychiatric patients (Excellence, 2011).

Non-attendance (no-show and drop-out) to these groups has been a long-standing problem (Barrett et al., 2008). Rates of non-attendance to groups has been reported to be between 19.7% (Swift & Greenberg, 2012) to 35% (Bostwick, 1987) and remains a significant problem for service provision (Swift & Greenberg, 2012).

'Virtual reality (VR) is a technological interface that allows users to experience computer-generated environments within a controlled setting' (Maples-Keller et al., 2017). People can now access VR through their smartphones being inserted into a head-mounted display (HMD), e.g. Samsung Gear VR. The prevalence of smartphone ownership among mental health patients is reported at 67% (Torous et al., 2014). VR may improve access to psychological treatments and reduce drop-out rates. It could become the method of choice for psychological treatments (Freeman et al., 2017).

A funding application was made to investigate the feasibility and acceptability of VR group therapy. In the study, the patients and the therapist would access the group remotely from home using an HMD with smartphone insertion. They would access the group therapy using the online application vTime (vTime, Limited, 2018). User involvement that will be described in this paper was conducted to guide the VR study design.

2. METHODS

2.1 Design

A participatory design was used. Two focus groups were held with patients and carers. The first was with an existing lived experience panel consisting of patients and carers and the second was with mental health patients living in the community.

2.1.1 Sample

Seventeen people participated in the user involvement. Eight patients/carers participated in the focus group with the existing lived experience panel. Half of the participants were female and half male. Nine patients took part in the second focus group. The majority of the patients were male (67%). No sample participated across groups.

2.1.1.1 Procedure

A five-minute presentation was made explaining the research idea: using VR to deliver remote group therapy. VR was described as a mobile phone connected to a headset to generate realistic images so that the user feels like they are in this pretend environment.

The existing lived experience panel was presented with the research idea and then had the opportunity to try the headset and the mobile phone application (vTime). Discussions included strengths and limitations of the study idea and recommendations were made on study design and methodology. The researcher made extensive notes of all the feedback. The meeting was held in June 2017 and lasted an hour.

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Funding was received (£350) to conduct the second focus group. A poster was created to advertise the three-hour focus group. This was tweeted online and emailed to existing lived experience panels. Patients who wanted to get involved contacted the researcher and confirmed their attendance.

The second focus group adopted a similar procedure to the first focus group. Differently, the patients were given a £25 gift voucher for their time and travel. The group was held in December 2017.

The notes from the focus groups were collated, and content analysis was used to identify themes.

3. FINDINGS

3.1. Importance of research question

Users highlighted that the study research question is of vital importance, the convenience of accessing group therapy from home may make groups manageable to patients, possibly leading to the improvement of attendance.

3.1.1. Study inclusion/exclusion criteria

Users were concerned that VR or the therapy may trigger hallucinations for patients with a diagnosis of psychosis. Therefore, it was recommended that the study excluded patients with psychosis and included patients with a diagnosis of depression. Furthermore, it was recommended that if the patients want to participate in other trials or therapies, they should not be excluded from the study, as this may lead to feelings of missing out.

Users highlighted that the elderly who may be physically restricted might enjoy/benefit from the VR group therapy and therefore recommended that the study not have an upper age limit as an exclusion criterion.

For pragmatic reasons it was suggested that patients who do not speak English and who do not have the necessary equipment (smartphone and wifi) are excluded from the study.

3.1.1.1 Recruitment strategies

As the therapy offered will be delivered remotely, it was suggested that recruitment should not be limited to clinics in the local trust but expand to surrounding trusts. As patients with a diagnosis of depression may not necessarily be treated by a psychiatrist, it was advised that recruitment incorporates primary care (e.g. GP's and talking therapy groups) and mental health charities that patients may be attending.

The users recommended that a risk assessment of potential participants should be conducted. However, they did not identify what would be classified as a risk and whether or not these patients should be excluded from the study. Incentives for assessments (e.g. vouchers) were recommended to maximise recruitment into the study.

3.1.1.1.1 Study design

It was recommended that VR groups have different timings (weekdays, evenings and weekends) and the patients are given a choice to select a time that is convenient for them.

It was advised that the first and last five minutes of each session should be dedicated to the therapist transitioning people in and out of the virtual environment. Breathing exercises were recommended for the adjustment period at the beginning of the therapy, and a gradual approach (patient removing the headset first and then the headphones) was recommended for the end of the therapy.

The group therapy may evoke certain emotions in patients. Therefore it was advised that the therapist should provide after session support by giving a courtesy call to patients who may need it.

As the patients will be accessing the group remotely using VR technology, it was advised that a study book is created. It was suggested that this book contains simple picture instructions on how to access the VR group, the time and dates of the sessions, with any planned breaks (e.g. Christmas holidays). Additionally, it was advised that the book has the contact details of the therapists and in case of emergency contact details of 24-hour crisis helplines. It was suggested that this book and patient documents is co-produced with further user involvement.

4. DISCUSSIONS

The user involvement has highlighted that the VR study research question is of vital importance. The users have informed the study design, recruitment criteria and recruitment strategies for the study.

5.1 Strengths and limitations

The user involvement incorporated a large sample (N=17) of patients and carers. This may have increased the variety, and quality of feedback received. However, extensive demographic details of the patients (e.g. diagnosis, age) were not collated. Furthermore, the group discussions were not audio-recorded for transcription. Instead, there was a facilitator present in both focus groups with the responsibility of taking extensive notes.

5.1.1 Comparison with literature

The Department of Health recommends patients and carers to be actively involved in every appropriate stage of research (Department of Health, 1999, 2005). It is now a requirement for research funding applicants to demonstrate how they have involved users in the development of their proposal and what their plans for continued involvement are (Barnes & Cotterell, 2011).

Incorporating patient perspectives into research can be challenging, as there are fundamental differences in stakeholder viewpoints and motives. Patients' views are inherently experienced based, and their motivation for involvement may derive from their wishes to bring about change and improvement to services. Whereas researchers' perspectives may be based on how to conduct the research pragmatically and their motivations may reflect their role, e.g. receiving funding (Barnes & Cotterell, 2011).

To overcome this challenge, it is recommended that researchers adopt a positive attitude (Thompson et al., 2009), and are transparent about their motives (Telford & Faulkner, 2004). Furthermore, it is recommended that both the researcher and the users' receive training. Researchers should receive training on communication skills and how to successfully conduct user involvement and patients to be trained in research (Thompson et al., 2009).

Through the presentations, the researcher was transparent that the study structure would follow research guidance to increase the potential of receiving funding. The users were not specially trained to be involved in this project as what makes user involvement unique is the contrasting perspectives and training may reduce the uniqueness of user perspectives and align them to the researcher perspectives (Barnes & Cotterell, 2011).

Offering patients reimbursements for their time and travel is a fundamental principle of user involvement (Ramon, 2000). As a result of this, user involvement can be resource intensive (van Wersch, 2001). This may be challenging if the research is in its development phase and no funding is available for user involvement. In the first instance, the research idea was presented to an established involvement panel that provides feedback on projects free of charge. However, as there is growing recognition in patient perspectives, there are small grants available to help fund patient involvement (Telford & Faulkner, 2004) and this project later received a small grant to conduct the second focus group.

Researchers may be sceptical of involving users as there is no concrete evidence that it has a positive impact on the research (Barnes & Cotterell, 2011), it is too difficult, costly and time-consuming to conduct (Boote et al., 2002). User involvement in this project was initially conducted to fulfil funding requirements. However, once the positive contribution the involvement had was observed, more patient involvement was conducted, and more involvement is planned throughout the project.

5. CONCLUSIONS

A participatory design was used to involve patients and carer in the development of the VR treatment group project. The involvement highlighted the importance of the research question, and the users helped to refine the projects design, recruitment criteria and recruitment method. The study has received funding and is expected to be completed by 2020.

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Towards a diagnostic Internet of Medical Things: Sensor-based data for sensory deficits in children with autism

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ABSTRACT

The Internet of *Medical* Things (IoT) is still developing into a fully-fledged technological solution for healthcare; there are examples of interventions and therapies and attempts to integrate assessment of symptoms or functions. We explore one potential application of IoMT: how sensor-based data could be leveraged for in-clinic diagnostic purposes, with children with autism and co-morbid sensori-motor dysfunction. We discuss the reasoning behind investigating this area, establish patient and professional need and suggest a practical technological solution.

1. INTRODUCTION

Children with autism demonstrate random, odd or inappropriate interaction with objects, which is only ever recorded through observation, or when screening and diagnosis occurs (e.g. ADOS, Lord et al., 2012). Sensory atypical behaviours are reported in 92% of children with autism, and 67% of children with a more general special educational need, showing the wide impact of sensory dysfunction (Green et al., 2016). For example, a child with autism may closely inspect an object such as a toy briefly before lifting it high over their head and shaking the toy from side to side, before returning to closely inspecting the item again. When a child interacts with an object such as a toy, variation in play presents an opportunity to automate capture of clinically meaningful data and provide clearer diagnosis for early onset, which is currently lost data to clinicians.

1.1 Object Interaction and Autism

Object play is found across humanity, and as well as co-occurring amongst other mammals and higher primates, it is thought to serve a deferred function for later in life activities such as foraging (Pellegrini, 2004). Play is also considered to be an important socio-cultural aspect of children's development that enables children to foster creativity, observe and understand the world about them, mimic others, experiment, get and hold attention, enhance concentration, and expand natural curiosity (Auerbach, 1986). Object interaction remains central to many autism diagnostic tools e.g. Autism Diagnostic Observation Schedule (Lord et al., 2012), and is reflected in the Diagnostic and Statistical Manual fifth edition (American Psychiatric Association, 2013) (see table 1). Further, children with autism experience difficulties in understanding and in how to use objects flexibly in social situations (Williams et al., 1999). Object use is often a social process which children with autism find difficult (Williams et al., 1999). The functional or sensori-motor use of an object is easier for a child with autism to understand than that of symbolic use (Rowland, 2009). Playing with objects can be repetitive and often inflexible with low levels of exploratory behaviour, proximal senses such as touch with the hand or mouth are favoured to gather information as opposed to auditory or visual means (Williams, 2003), and without a clear understanding of the functional use of an object, features and aspects often become fixated upon (von Hofsten et al., 2009).

1.2 Impaired Sensory dysfunction

Sensory behaviours such as tactile sensitivity, general dysfunction in sensory interests, under or over-responsiveness to stimuli are abundant within ASD atypical behavior. Even so, whilst dysfunction is associated with greater sensory need, earlier versions of the diagnostic and statistical manuals (DSM IV and IV-TR) have not included specific references to sensory responsiveness, mainly due to a lack of understanding of the sensory problems associated with autism (Green et al, 2016). Animal modelling shows it is likely that tactile sensitivity outside the normal range is as a result of underlying somatosensory dysfunction, a result of deletions in *Mecp2, Gabrb3, Shank3* and *Fmr1* genes (Orefice et al., 2016). Further, loss of GABAa input to the central nervous system occurs only in infancy and not adulthood, but later presents through deficits in social interaction and anxiety (Orefice, 2016). This evidence suggests autism resides not only within brain structure, but also has a real and later co-occurring impact on the

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development of sensory receptors, so much so that reaction to touch becomes a strong reinforcing model for later inhibited social interaction and tactile actions.

Table 1. *Extract from the Diagnostic and Statistical Manual V for Autism.*

DSM-V Section B
1. **Stereotyped or repetitive** motor movements, **use of objects**, or speech (e.g., simple motor stereotypies, lining up toys or flipping objects, echolalia, idiosyncratic phrases).
3. Highly restricted, fixated interests that are abnormal in intensity or focus (e.g., strong attachment to or preoccupation with **unusual objects, excessively circumscribed or perseverative interest**).
4. Hyper- or hyporeactivity to sensory input or unusual interests in sensory aspects of the environment (e.g., apparent indifference to pain/temperature, adverse response to specific sounds or textures, **excessive** smelling or **touching of objects,** visual fascination with lights or movement).

1.3 Impaired "micro-movements"

Torres et al (2013) argue that small fluctuations or "micro-movements" in the way that individuals with ASD interact with objects in their environment begins as stochastic, dynamic and heterogeneous developmental processes in typical maturation but gradually becomes disrupted in autism. Random activity early on in life typically takes on a more logical and goal directed trajectory during maturation, but individuals with autism retain more goal-less activity – alongside the development of compensatory strategies. Behavioural variability in micro-movements for autism remains unpredictable and less exploratory compared to typical individuals. Behaviours in autism are therefore symptomatic of active coping strategies (Torres et al., 2013). As children with autism grow older they retain ways of interacting with objects that may look odd or repetitive e.g. a preoccupation with parts of objects or undifferentiated play that endures longer than expected (e.g. see Williams 2003). Compared to typical peers, earlier forms of interaction that are more random and less focused remain beyond childhood. Rowland and Schweigert (2009) show that children with autism interact with objects differently, classifying behavior according to the way objects are obtained, practically used, socially used and representationally used. Dominguez, Ziviani and Rodger (2006) show that children with ASD take part in more relational play of objects (combined in non-functional and non-symbolic ways) more sensorimotor and exploratory play in 3-7 year olds than typical peers.

2. INTERNET OF MEDICAL THINGS

As our understanding of both ASD and sensory dysfunction increases, this parallels potential capability of sensor-based technology to unobtrusively gather data. Whilst traditional toys are estimated at a global value of 160.96 billion dollars, the video game /screen based industry is worth 103.29 billion dollars, and by 2025 screen based video games and toys will overtake traditional games to be worth 249.61 billion dollars as opposed to 237.82 billion dollars (PWC 2012, accounting for yearly percentage increase). Play is due to change as objects being played with by all children will alter as toys will be more technologically enhanced. This means that objects will need to be smarter as more time is due to be spent using them.

Attempts have been made to harness and classify children's play with enhanced toys and games by (e.g. Farr et al 2012). Other attempts to use sensor-based toys have been developed to be therapeutic, and play has been used as a mode to investigate the pathology of autism, develop self-concepts, personality adaptation, self-recognition of elevated states (e.g. anxiety, hyperactivity, over stimulation) and develop problem solving skills (Tseng et al., 2016). Tseng et al (2016) developed therapeutic toys for autistic children, with the focus on captivating the interest of children. The toys focused on critical design themes of engaging and encouraging cooperative play, thereby captivating the interest of autistic children. Other advances in technology for autistic children tend to focus on the regulation of perceived deficits, e.g. static functional performance in contexts such as virtual reality, video or software applications (Kientz et al, 2013), or in the use of wearable technology for self-recognition and reflection. Use of technological objects that are useful in dynamic and real-life settings, bring technology closer to activities of daily living and so are necessary to be able to create meaningful and positive experiences for individuals with autism (Spiel et al, 2016). As explained by Torres et al (2013) any developed object or intervention requires a participatory approach to improve interaction and elicit valuable data about children whether typical or atypical. Sensor data can be acquired about the way children interact with toys, and mapped to developmental markers (such as DSM V). Patient and public involvement carried as part of pilot work indicates parents understand the use of physical toys more readily than screen-based interaction as this is more aligned to their own childhood. Further, this work on sensor-based data in toys runs in parallel with the development of screen-based diagnostic tools by the author and colleagues (e.g. see Jordan et al 2016).

2.1 Population Benefits

The World Health Organization International Classification of Functioning, children and young people's edition (ICF-CY) focuses on those activities that enable individuals to have a high amount of personal control over their lives (WHO, 2001). The ICF-CY arranges issues into areas of 'impairment', 'body structure and function', 'activities', and meaningful activities such as 'participation'. Areas include assisting in focusing (b1140 - b1144), orientation to time, place, person, objects and space by increasing interest and motivation, assisting with (b1250-1254) improved adaptability, responsivity, activity level, predictability and persistence through game playing, improved agreeableness (b1261, improved (b1301) motivation, attention (b1400) and helping to regulate impulse control (b1304). For families, happiness, anxiety and sensory overload were those areas considered to be important outcomes in a clinical situation (McConachie et al, 2015). Any tool that could be employed into a clinical situation to increase engagement whilst gathering useful information about a child adds value to clinical interaction.

2.2 Participatory Pilot Work

To explore types of objects that could be used to house sensors we conducted early pilot work with a group of 6 ASD and 6 typically developing children within two 30 minute free play sessions using mudrock (a clay that hardens after one hour) as an initial play tool to give ideas about the types of shapes that would be appealing for children with autism. Children chose to make a variety of objects from clay which echo some of the universal types found by Galimberti (2017). Universal elements map which words map to what object (Ozge, Krehm and Vououmanos 2013) and children like to infer meaning on objects regardless of the housing (e.g. Samuelson and Horst, 2007). This finding has often been echoed in human computer interaction research with children (Randall et al 2003). As a result, the type, and frequency of objects that will house the sensors will be explored in future focus groups.

2.1 Sensor Types

A number of solutions will need to be tested. Inertial Measurement Units such as Bluetooth will be used initially for the data gathering as they provide high fidelity data with good accuracy, high sampling rate and work well in combination with other sensors (Bulling et al., 2013). However, IMU is good with only a few objects and so passive ultra-high frequency radio frequency identification tags may an alternative as it is good with multiple objects over a variety of frequencies (e.g. Li et al., 2015). Pilot work found that the potential type of movements that are likely occur and could be used as a baseline for assessing diagnostic variation may include, rotation, swipe touch/movement, covering touch/movement, linear movements along one x,y,z axis (linear motion), reciprocating movements e.g. moving backwards and forwards in a straight line, stillness, where there are long periods of no contact, multiple touch events, and oscillating movement e.g. swinging from side to side, It is also anticipated that input and output movements may differ, so one movement may begin as one type of movement and end up as another.

3. CONCLUSIONS

The way in which an object is picked up, turned over, how long it is held for, or how it is held, is currently not captured in any way, whilst it is thought that 92% of children with autism are outside the normal range of tactile sensitivity. We aim to map out and investigate this research space through the use of sensors such as IMU Bluetooth, which can tell us how children are interacting with objects, and how this diverges from neurotypical children. A new methodology for characterizing and organizing sensori-motor impairment will allow clinicians to be able to see type, time, and duration of object handling. Capture and classification of objects will enable severity of manual handling that is outside normal ranges to be identified. Borderline diagnosis and confusion could perhaps be avoided, as harvested data could then be used in addition to observable reports. It is possible that this work could lead to improved engagement for children, and better clinical productivity, as children are interacting in a natural manner through play. This solution could also lead to the development of a supplementary framework through software visualization that look at periods of children's play with toys or objects, and begins to characterize and classify. The challenge of using sensor-based toys will be the integration and acceptability of data harvested into clinical interactions which are ecologically sound and do not change, hold up, or significantly impact the way a child or parent interact in a clinical environments whilst engaging with professionals.

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Plausibility and weight classification of 3D avatars from egocentric and allocentric perspectives. A preliminary study in healthy women

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ABSTRACT

The use of 3D virtual avatars could help to overcome the limitations of conventional methods to assess body experiences related to self-identification and first-perspective. This study evaluates the plausibility (the extent to which avatars might exist in the real world) of a set of avatars with different BMIs, in egocentric and allocentric perspectives in a sample of 44 healthy women. Results show the plausibility of the avatars, their accurate classification in different weight categories, and support their use as reliable and valid alternative to be used in the assessment of body experiences.

1. INTRODUCTION

One of the most common characteristic of individuals with eating disorders is alteration of body experience, (APA, 2013; Fairburn, 2003). Several methods have been developed in order to evaluate distortions in body experiences, including body size estimation and ideal body size estimation (Moussally et al, 2017). The more common procedures to assess these experiences include the presentation of drawings and photographed silhouettes in a paper, as well as 2D-3D figures in a screen. Although these methods are easy to administer, the have some limitations that might affect the results. First, figures and objects are insufficiently detailed. Second, only a third-person perspective (allocentric) is considered. However, we experienced our body (and the world) from a first-person (egocentric) perspective. Third, small differences and profiles may exist between figures in terms of body mass index (BMI). Finally, limited self-identification with bidimensional figures could alter the results (Gardner et al, 2009).

The capacity of virtual reality to provide multisensory stimulation and real-time user interaction in simulated environments (Bermúdez i Badia et al, 2016) has promoted its use in a wide range of applications (Borrego et al, 2016; Ventura et al, 2018). As virtual environments (VEs) can be mediated by virtual avatars, importance of virtual reality not only relies on the opportunity to modulate the environment, but also to modulate the body with which we perceive and interact with the environment (Fonseca-Baeza et al, 2018).

We hypothesize that the use of 3D virtual avatars instead of the conventional 2D figures of common methods or 3D figures presented on a screen, would improve the assessment of body experiences. However, the validity of virtual avatars to realistically represent different body mass indices (BMIs) and the effect of using different perspectives are unknown. The objective of the study was to determine the plausibility of a set of avatars with different BMIs, that is, the extent to which avatars might exist in the real world, in both egocentric and allocentric perspectives.

2. METHODS

2.1 Participants

Healthy women from 18 to 35 years were recruited from the Universitat de València community. A total of 44 participants with a mean age of 21.46±2.00 years old and a mean BMI of 21.93±2.43 agreed to participate in the study. All of the participants provided written informed consent before taking part in this study. Ethical approval was obtained from Universitat de València.

2.2 Instrumentation

Nineteen female virtual avatars, each one corresponding to a different BMI in the range of 12.5 to 30.5 (in steps of one) were designed for this study. Avatars had a height of 1.65 cm and an approximate age of 25 years old to resemble the participants' characteristics. BMI variation was accomplished through changes in percentage of muscle mass, percentage of fat mass, and proportion between different body parts trying to maximize the likelihood with real human bodies. Avatars were designed on MakeHuman (www.makehumancommunity.org), an open source software that allows for creating 3D human models with a wide range of physical characteristics.

Visual feedback was provided by an Oculus Rift HMD (Oculus VR, Irvine, CA). The device has a resolution of 2160x1200, a field of view of 110 degrees, a refresh rate of 90Hz and provides head tracking through a built-in gyroscope and accelerometer (Borrego et al, 2018). A high-end computer was used to generate the VE. The hardware components of the computer included a 4-core Intel® CoreTM i5-7640X @ 4.00 GHz, 16 GB of RAM, and a NVIDIA® GeForce® GTX 1070Ti with 8GB of GDDR5.

The VE consisted of an infinite checkered floor with a female avatar in the center. Both egocentric (Figure 1.a) and allocentric perspectives (Figure 1.b) were enabled. In both cases, the upper part of the VE was used to present a multiple choice survey question. The Oculus Touch controllers (Oculus VR, Irvine, CA) were used to choose the proper answer. The VE was designed using Unity 3D (Unity Technologies, San Francisco, CA).

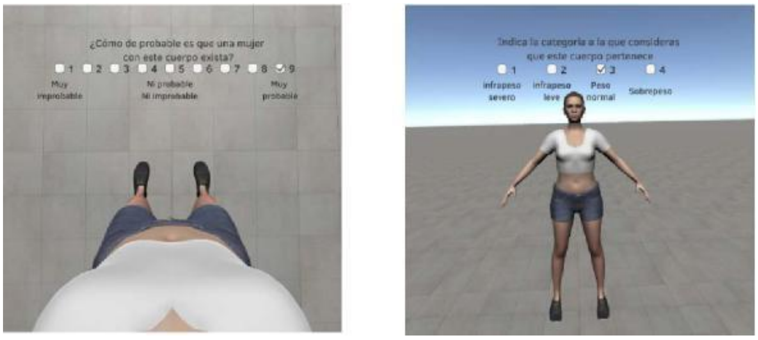

Figure 1. *Virtual avatar in a) egocentric, and b) allocentric perspective*

2.3 Procedure

Participants were initially equipped with the HMD and the controllers and were briefly introduced to the experiment. The set of avatars were presented from a first and third-person point of view, in random and counterbalanced order. For all the avatars, participants were required to: (1) evaluate the extent to which they could exist in real life in a Likert scale ranging from 1 (very unlikely) to 9 (very likely). Experimenters specifically clarified that the question was not asking to evaluate the body, but the likelihood of that body to exist in the real life. In other words, whether the body proportions are plausible in the real world or if they are unreal and could only be part of a virtual avatar; and (2) to choose the category of the BMI proposed by the World Health Organization (severe underweight, mild underweight, normal range and overweight) that better fitted the avatar (WHO, 2013).

2.4 Data Analysis

One-sample t-tests were conducted to analyse the avatar plausibility. The effect size was calculated using Cohen's d. Pearson's correlations between the plausibility in both perspectives were computed. All analyses were conducted with SPSS for Windows, version 22 (SPSS Inc., Chicago, USA).

3. RESULTS

3.1 Plausibility

The avatars were evaluated as being plausible on average from both egocentric (M = 7.82, SD = 1.04; significance of the difference from the central score [5] of the Likert scale , $t(43)$ =18.03, $p < 0.001$, d = 2.72) and allocentric perspective (M=7.49, SD=1.37; significance of the difference from the central score of the Likert scale , $t(43)$ = 12.075, $p < 0.001$, d = 1.82,) (Figure 2.a). In addition, a moderate correlation emerged between plausibility scores in both perspectives (r =0.504, $p < 0.001$).

Avatars that were evaluated from an egocentric perspective were believed to be more plausible than those observed from an allocentric perspective (Figure 2.a). This was also evident when avatars were grouped by BMI categories (Figure 2.b). Severe underweight avatars were believed to be the least plausible, followed by overweight avatars. Underweight and "normal-weight avatars were assessed as the most plausible.

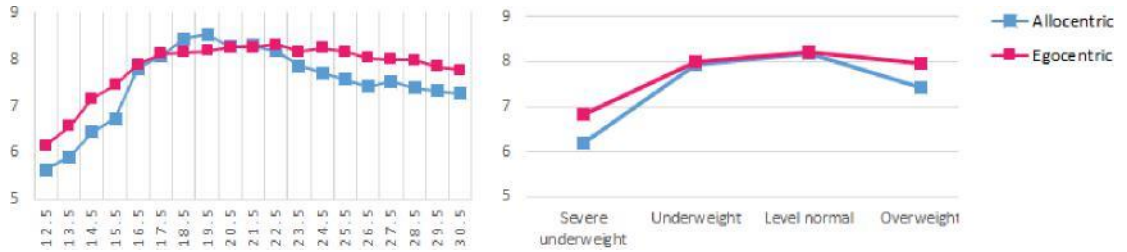

Figure 2. *Mean plausibility for a) each avatar and b) avatars grouped by WHO categories.*

3.2 Weight classification

Statistically significant differences were found among the four classifications for both perspectives (Table 1). The classification of the avatars is shown in Figure 3.

Table 1. *Mean plausibility, significance of the difference from the center of the evaluation continuum and effect size of the avatars according to WHO categories.*

	Perspective	Mean (SD)	t(43)	d
Severe underweight	Egocentric	6.84 (1.77)	6.86**	1.04
	Allocentric	6.18 (2.34)	3.35*	0.51
Mild underweight	Egocentric	8 (1.25)	15.942**	2.4
	Allocentric	7.93 (1.63)	11.90**	1.31
Normal range	Egocentric	8.22 (0.94)	22.66**	3.42
	Allocentric	8.18 (0.86)	11.90**	3.69
Overweight	Egocentric	7.96 (1.23)	15.92**	2.4
	Allocentric	7.41 (1.83)	8.76**	1.32

p = .002, *p < .001, *SD*=Standard deviation, *d*=Effect size (small≈0,2, moderate≈0,5 and large≈0,8)

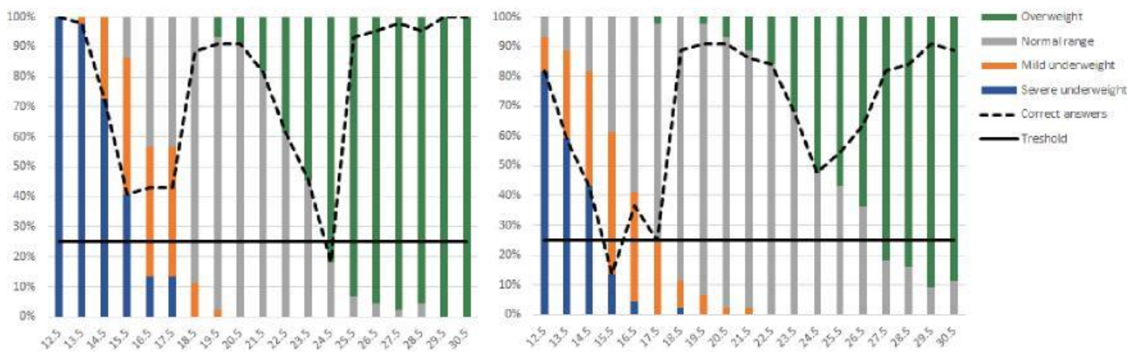

Figure 3. *Classification of the avatars according to WHO categories in a) allocentric and b) egocentric perspective. The percentage of correct classifications for each avatar is indicated with a dotted line. The random classification threshold in 25% (i.e., 100/4 possible responses) is marked with a solid line.*

4. DISCUSSION

Plausibility was confirmed in both egocentric and allocentric perspectives, and the results in these two conditions showed moderate correlations. It is important to highlight that severe underweight avatars were judged as being less plausible than avatars around a normal weight range and overweight avatars, which could be explained because they are less frequent in the general population (Penman and Johnson, 2006). Avatars were, on average, correctly classified in the different BMI categories in both perspectives. Accuracy decreased in those avatars with borderline BMIs, which could be considered ambiguous (BMIs 15.5, 17.5 and 24.5) (Moussally et al, 2017). These preliminary results evidence that avatars can be considered plausible and be accurately classified in different weight categories, which supports their use as in VEs.

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The feasibility and initial effectiveness of TECH to improve cognition: Tablet enhancement of cognition and health intervention

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ABSTRACT

This study examined the feasibility and initial effectiveness of 'Tablet Enhancement of Cognition and Health' (TECH) a novel cognitive intervention utilizing touchscreen tablet applications for self-training for older adults with Mild Cognitive Impairment (MCI). Thirty community-dwelling older adults with MCI were recruited to participate in a single-blind randomized controlled trial. Participants were allocated into TECH (N=16) or standard care intervention (N=14). Feasibility was high and initial effectiveness (pre versus post) was found.

1. INTRODUCTION

Cognitive decline in older adults, including Mild Cognitive Impairment (MCI), is a main concern for health systems worldwide (World Health Organization and Alzheimer's Disease International, 2012). MCI is an intermediate stage of cognitive impairment that is often, but not always, a transitional phase from normal ageing cognitive changes to dementia (Petersen et al., 2014). Currently, there are no pharmacological interventions recommended for improving cognition of adults with MCI. Hence, cognitive interventions that can be implemented as treatment for individuals with MCI should be examined (Williams, Plassman, Burke, Holsinger, & Benjamin, 2010). Cognitive training using technology such as computer software and computerized puzzle games is being investigated increasingly in recent years (Martin, Clare, Altgassen, Cameron, & Zehnder, 2011), and found to have potential to address this issue, especially cognitive training using tablet applications, which may be fun and motivating. Our study objectives were: 1) To assess feasibility of Tablet Enhancement of Cognition and Health (TECH) a novel cognitive intervention utilizing tablet applications for self-training for older adults with MCI and, 2) to assess the initial effectiveness of TECH, for improving cognition of older adults with MCI compared to standard care.

2. METHODS

2.1 Study Design

A single-blind pilot randomized controlled trial with assessments administered pre and post the 5-week intervention, by assessors blind to group allocation. Other occupational therapists carried out the intervention.

2.2 Population

Individuals were older adults (>65 years), who lived in the community and reported memory problems. Inclusion criteria; Mild cognitive impairment (MCI), were independent in Basic Activities of Daily Living (BADL) and Instrumental Activities of Daily Living (IADL), had normal or corrected vision and hearing, spoke, wrote and read Hebrew, and were able to understand and follow the use of a touchscreen tablet after initial demonstration. Individuals were excluded if they experienced severe depressive symptoms, and if they were diagnosed with dementia, or other neurological or psychiatric condition.

2.3 Tools

2.3.1 Feasibility of TECH. Feasibility was assessed by **Adherence and Satisfaction** from the program**. Adherence was assessed by** Self-training time – minutes a week, taken from participant's daily logs, and Attendance in the six weekly-group sessions. **Satisfaction** from the intervention was determined by a questionnaire, developed for the study. The questionnaire includes 15 questions, 10 of them on 1-5 scale (for example: How much did the self-training motivate you to make an effort?), and 5 of them on 1-3 scale (for example: Is TECH too long / too short or just the right length?). Participants were characterized in terms of demographic information, and prior tablet experience.

2.3.2 Effectiveness. The primary outcome measure was **the Montreal Cognitive Assessment** (**MoCA**) (Nasreddine et al., 2005) to assess global cognition. This is valid and reliable cognitive screening tool, with high sensitivity and

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specificity, that assesses eight cognitive domains. The secondary outcome measures were **WebNeuro** (Silverstein et al., 2007), a computerized web-based battery assessment of neurocognitive functioning to assess executive functions and the **Tower of Hanoi (ToH**) (Welsh & Huizinga, 2001) task which is a commonly used goal-directed measure assessing problem-solving, and planning.

2.4 Interventions

2.4.1 TECH intervention (the experimental group) -includes daily self-training using tablet applications (apps) facilitated by six weekly group sessions.

Self- training took place independently at the participants' home and included mostly playing puzzle-apps for training different cognitive components. Puzzle-apps require executive functioning (such as planning, problem solving, cognitive flexibility) and therefore have the potential to be used as tools for training these cognitive components (Givon Schaham, Sternberg, & Rand, 2018). Examples of apps used are shown in figure 1. Participants were requested to play various apps three to five times a week for 30-60 minutes each time, for a total of 15-25 training sessions. In addition, they were encouraged to use the tablets for a variety of everyday uses such as banking, news reading, on-line information seeking, social networking etc. For monitoring self-training time, participants were requested to log their training time, apps used, and whether they needed assistance during the training.

Weekly group sessions - the self-training was facilitated by six weekly sessions (of 60 minutes) in a small group setting (5-6 participants) led by an experienced occupational therapist. Sessions focused on tablet operation, exploring and practicing new apps, practicing tablet and internet functions, relearning of previous apps for increasing the ability for self-operating, and obtaining feedback from the past week. Each participant also received a manual with explanations and photographs of tablet and app operation. The training sessions also facilitated social interactions and provided social support in order to enhance motivation. The Satisfaction questionnaire was administered following the last group session

2.4.2 Standard care (Control group). Participants in the control group participated in a single group session, to receive guidance and encouragement to engage in activities that can stimulate their brain such as solving crosswords puzzles, playing board and card games. No manual was provided and no follow-up was conducted.

2.5 Statistical Analysis

By using IBM SPSS statistics software, version 24 (Armonk, NY, USA), descriptive statistics were used to characterize the sample, feasibility and outcome measures pre and post the intervention. Mann-Whitney and Wilcoxon, non-parametric tests, were performed to examine the differences in demographic and cognitive characteristics between the groups before treatment, the differences within each group between pre and post, as well as the differences between the groups in percentage change over the treatment period. In addition, effect size (Cohen's r for non-parametric tests) was calculated for the different outcomes.

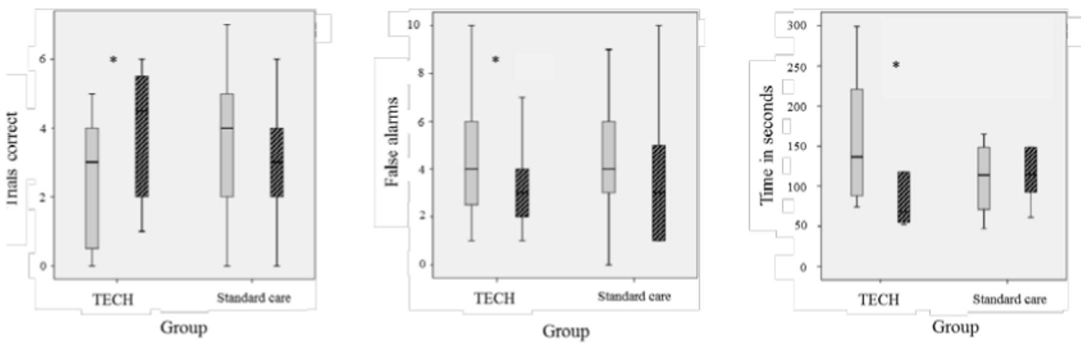

Figure 2. *Median (Inter Quartile Range) of Executive functioning subtests; Digit Span, Go / No-Go and TOH pre (grey) and post (black) of the TECH group versus the standard care group*. ** significant difference, p<0.05.*

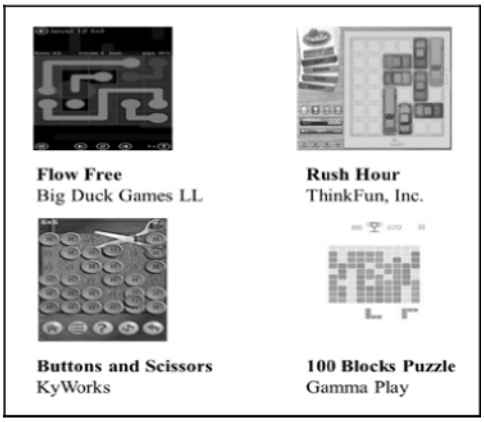

Figure 1. *Examples of apps used for TECH self-training – Name and Company*

	TECH n=16 Median (IQR)	**Standard care n=14 Median (IQR)**
Digit Span Correct Trials	3.5 (4.7-1.0)	4.0 (5.0-2.0)
Go/No-Go # False Alarms	4.0 (6.5-2.2)	4.0 (7.0-2.5)
TOH level 2/3 (secs)	2.00 (3.0-1.0)	1.5 (2.0-1.0)
MoCA (0-30)	22.5 (20.2-23.7)	21.5 (20.0-24.0)
TMT Completion Time (secs)	103.9 (141.3-84.5)	111.8 (190.6-105.7)
Maze Learning Time (secs)	412.0 (284.1-564.6)	420.5 (276.4-580.7)

Table 1. *No significant differences in Executive functioning between groups prior the intervention*

3. RESULTS

Thirty participants with MCI were recruited into the study. Seven women and nine men aged 70-87 (median age 76) were allocated to the TECH intervention group. Five women and nine men aged 86-68 (median age 74.5) participated the standard care group. During the intervention, one TECH participant and three standard care group participants dropped-out due to deterioration in health condition and due to lack of interest (respectively).

3.1 Feasibility of TECH

Adherence was high; participants self-trained on average 19.2 training sessions over the five weeks, training time varied from 9.25-39.75 hours with mean training time of 20.5 hours over the five weeks training. All participants attended at least 80% of the group sessions. 86.6% of the participants reported a very high satisfaction with the program and that the exercise motivated them to make an effort for a great extent. 85.2% reported that they would be interested in continuing their own practice with tablet devices at the end of the treatment period.

3.2 Effectiveness

Groups were similar pre intervention ($p>0.05$) in terms cognitive and executive function ability, as shown in Table 1. Post intervention, as shown in figure 2, TECH group showed statistically significant improvements in two sub-tests in the WebNeuro: an increase in the number of correct sequences in the Digit Span sub-test ($z=2.10$, $p=.04$) and a decrease in the number of errors in the Go / No-Go sub-test ($z=-1.95$, $p=.05$). A decrease in completion time of level 2/3 in the TOH test was also found ($z=-2.19$, $p=.03$). Improvement in the MoCA and time to complete Trail Making Test (Part B) and Maze WebnNeuro sub-tests, were seen but they did not reach statistically significance and were sometimes observed in the control group as well. Medium effect sizes were found in additional WebNeuro sub-tests such as TMT ($r=.23$) and Maze ($r=.35$), indicating a positive trend for the TECH group.

4. DISCUSSION

Touchscreen tablet puzzle-apps entail the use of executive functioning and involve the learning of operating a new technology, which also encourages the use of different cognitive functions. TECH intervention, based on daily self-training, was found to be feasible for older adults with MCI, who managed to operate the tablet independently and trained on average 19 hours over five-week intervention (3.8 hours per week). Participants were highly satisfied with the intervention, which is in accordance with the improvements in executive functions in these participants in working memory, planning and problem solving compared to participants in the standard care group. In addition, TECH intervention improved planning and problem solving (TOH test) (with high effect size) and general cognitive function (MoCA) (with moderate effect size), without statistical significance.

These findings are consistent with other studies assessing cognitive interventions effectiveness, integrating the use of technology (Gaitán et al., 2013) [tablets (Djabelkhir et al., 2017) and computers (Hill et al., 2016; Tetlow & Edwards, 2017)]. The use of technology motivates the user and encourages intense and accessible training (Djabelkhir et al., 2017; Kizony et al., 2016; Ramprasad et al., 2017). These preliminary findings are very positive but need to be supported by further research including a larger sample and follow-up assessments.

5. CONCLUSIONS

TECH is a feasible intervention for older adults with MCI. The touchscreen tablet puzzle apps motivated the participants to train independently which lead to positive findings in executive functions, which were not seen in the control group. Further research is needed to establish the effectiveness of TECH intervention in maintaining and improving cognitive function of older adults, who are at risk of cognitive decline.

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Open world memory game

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ABSTRACT

Memory games have multiple purposes. It is possible to play memory games to entertain oneself, however it is also possible to use them to improve the cognitive skills of people with disabilities. The purpose of this study was to develop a new type of memory game – an open world memory game – not only to have a new take on the playability of memory games but to try a different method to improve the cognitive skills of people with disabilities.

1. INTRODUCTION

Memory or concentration games are mostly card games where two or more players compete against each other with their memory skills. The requirement of victory is a good memory, but it is not enough by itself. Provided that the memory skills of the players are the same (or at least are similar), the method of playing the game may change and strategy becomes the main factor (Zwick, 1993). Traditional memory game is a perfect example where the known cards are the first ones to be taken out of the game while the player gains points against their opponent. However, in most cases memory games consist of two phases. In the first phase some elements are shown to the player which can be pictures, sounds, animations – or the most popular: cards. In the second phase an objective is given where the seen or heard elements must be used to successfully complete the game.

Memory games give a good basis for research purposes as they are known in the entire world, can be easily learnt, are scalable and have positive effects on the user. One particular study (Zwartkruis-Pelgrim, 2008) was conducted with the help of elderly people where memory games were developed for them. The aim of that research was to maintain or to improve the memory and learning skills of the elderly people. The cognitive skills develop until the late thirties or until the early forties then stagnate until the year of fifty or sixty. After the ages of fifty or sixty the cognitive skills start to degrade. After the said study, improvement has been diagnosed and people became committed to the games which have increased their performance. As a result, they wanted to play the game even more. In conclusion, it can be said that practice improved the cognitive skills of people who have played the games on a regular basis.

Figure 1. *The Frog Simon Game* [Zahari et al, 2014].

In the case of stroke patients, physical or cognitive problems may possibly arise. The loss of memory is a typical example for these types of problems. The patient cannot remember their name or something from their past. There have been studies in the past regarding this subject. Zahari et al (2014) developed “The Frog Simon Game” for this exact purpose. In the game, there are four buttons. During playing, the application presents multiple iterations of light effects and sound effects. Every turn, the difficulty of the game increases as length of these iterations increases by one. The objective of the user is to reproduce the seen and heard sequence of each iteration with the help of the four buttons. This allows the memory of the user to be tested.

Rehabilitation and treatments also exist in the world of virtual reality. Virtual reality technology also allows the user to feel more calm and relaxed while in a virtual environment (Hoffman, 2006). In the past, a virtual reality house was made for aphasic patients to help them with language problems (Horváth, 2009)

The purpose of this study is to develop a new type of memory game which can be called an open world memory game because it allows the user to navigate in a three-dimensional environment with the goal of not only entertaining, but also helping people with disabilities.

2. METHODS

Firstly, selecting the platform was the focus during development. The idea behind the thought process was that the application must be as accessible as possible, so the Microsoft Windows 7 (or above) operating system was chosen. Secondly, many types of memory games were tested. One of these games was The Frog Simon Game mentioned above. The pros and contras of these games were assessed. After testing multiple games, ideas became apparent for the open world memory game.

As mentioned before, both virtual reality and memory games allow rehabilitation or treatment processes for the user. The aim of the application is to take the pros out of both virtual reality and memory games and put it in the open world memory game. As it is a game with a 3D virtual environment, a game engine was needed. Unity game engine (Unity) was chosen because it is free to use and has the features of a paid game engine. For 3D virtual environments it is necessary to design 3D models. Most modelling software is compatible with the Unity engine. Blender software (Blender) was chosen for 3D modelling because it is easy and free to use. Blender also allows the users to make animations for the models and that can be imported into Unity.

There are language options for language learning purposes. For the same reason the game could be used for helping aphasic patients (Sik Lányi, 2006). The player can select English or Hungarian language in the game. While playing the memory game and selecting the individual items, the player can see the name of the items on the screen.

2.1 Functional requirements

The application should include the following:

- The most important functional requirement is that the game should be a memory game at its core.
- Random-generated order of items for the memory game, so each play-through is different.
- *Open world:* The game world should be freely walkable by the user at any time.
- Should have two language options: Hungarian and English.
- The player should see the names of the items on the screen in both languages.
- Increasing difficulty across levels.
- Ability to save and load the game.
- Should have a high score list.

2.2 Non-functional requirements

- Easy to use graphical interface.
- Can be easily played by anyone.

3. THE GAME

The game revisits the well-known memory game concept from a brand new approach. The game is called 3D Memory. It is a level based game, where the difficulty scales across levels, putting the players' memory skills to test in a brand new 3D environment: The game takes place in a virtual family home – the house of Peter Griffin from the show called Family Guy (Home of Peter Griffin from Family Guy) – where the player needs to interact with series of items (everyday objects) in the correct order, which the game randomly generates and provides to the player prior to the start of the game. Results are being monitored and saved by the game automatically, so the game can be loaded and continued from nearly the same spot where the player left it. Because of saving, player results can be compared, so the game provides friendly competition besides entertainment, challenge, and provides improvements in cognitive abilities.

Figure 3. *A room in the game.*

After opening the application, the users can find themselves in the main menu. The menu has five buttons, a Start New Game button, a Load Game button, a Results button, a Settings button and a Quit button. The buttons are self-explanatory. Inside the Settings menu four things can be changed: The language, the lighting, and showing the next room or animations can be toggled on or off.

When the user starts a new game or loads a saved game, he/she can find his/her character inside the game. The environment is freely walkable by the player, some items can even be interacted with. The game helps with the navigation and with the discovery of the items. As during the writing of this study the game is controlled by a keyboard and a mouse, the memory game can be started by pressing the "F" key if it is not already completed. The instructions can be seen on the top of the screen, which help the player completing the game.

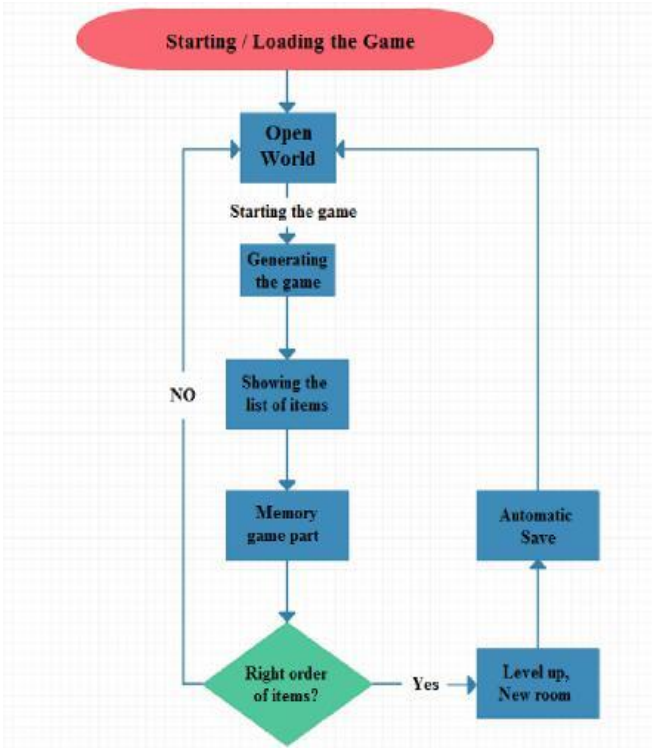

Figure 4. *The flowchart of the game.*

The game mode is a turn based memory game. A room name can be seen on the top of the picture. After pressing the "F" key, randomly generated order of items is chosen in the said room. This order can only be seen once by the player and the player must memorize the order. After the order disappears from the screen, the player must move the character across the room to the items in the correct order and must interact with them. This can be done by moving close to the items, and if the player can see the name of the item on the bottom of the screen, the "E" key must be pressed.

If a correct item is chosen, a sound can be heard, and the player can also see an encouraging text on the screen. This will continue until every selected item is correct or until one item is selected incorrectly. If every selected item is correct, a new room inside the house will be opened and a new memory game can be played inside the newly opened room. Otherwise, the memory game will stop, and the game will return to its open world format. The memory game can be restarted from the beginning by pressing the "F" key again.

The user does not have to worry about saving game as the application automatically saves by itself. It saves when the game starts, after the player levels up or before the player quits the game.

4. TESTING THE APPLICATION

As there is no such thing as perfect application, the game had to be tested as well. There is a great possibility that some functions do not work in the case of videogames and this fact decreases playability and immersion. Games are mainly made for entertainment and functions not working make the games much more frustrating for the players. Before sending the game to the testing group, the developers' team tested the application first and fixed the problems which they were able to find.

During the second phase of testing five undergraduate students tested the application. Each one of them tested the application on their own computers for a week, half an hour every day. They completed the game multiple times both in Hungarian and in English. The optimization of the game was tested as well. The game was stable on all testing computers, the framerate was always above thirty frames per second and on most computers the game had even sixty frames per second.

5. CONCLUSIONS

The completed application takes the well-known concept of memory games into a new, unknown environment. This uses new elements which make the game and the gaming experience more unique. Using multiple existing technologies, a family house was created. Inside this house, there are items which must be memorized and the players can freely interact with them during the open world section of the game. The user interface is user friendly, thus everybody can enjoy the game. Continuous feedback and instructions are given to the user. It is excellent for developing cognitive skills because of the increasing difficulty throughout the levels. Progression can be seen on the score list.

It is important to know that the application has the opportunity for further development: The game could further be improved by making it more accessible with adding movement recognition sensors like the Kinect or the Leap Motion Controller so it could be played by anyone. Regarding the structure of the game, as it is an open world game, only the creativity might limit the options. Numerous new functions and game elements can be added. For example, multiple environments can be made, so that the memory game could be played inside of a shop or a park. New assets can also be added to the existing environments. Even the game mode can be developed further: new levels and game modes can be added. Detailed interactions can be implemented, where for example the items can be moved. The possibilities are endless.

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Similarities between locomotion in virtual and real environments: Implications for rehabilitation

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ABSTRACT

Age-related impairments impede the ability of elderly persons to accomplish daily tasks in complex life situations. One of the main determining factors of participation in such activities is the ability to be mobile in the community. Virtual environments (VE) provide an ecological-valid context to evaluate the various aspects of performance of a complex task including locomotion. However the level of similarity between the real and simulated environments may differ between the various aspects of performance (e.g. motor versus cognitive). The purpose of this study was to compare gait performance and aerobic effort of young and community dwelling older adults during a complex daily activity in a real mall environment to performance in an identical virtual mall. Seventeen young and 16 older healthy adults performed the Multiple Errand Test in virtual and real world (RW) environments. Gait variables, heart rate (HR) and perceived exertion were recorded. The results showed that gait speed and HR were higher in the RW environment whereas perceived exertion of the older group was higher within the VE. In addition, gait variability was higher in the VE. The results indicate that performance in the real environment involved higher motor effort than within the VE, regardless of age.

1. INTRODUCTION

Age-related impairment of cognitive, motor and physiological processes, individually or in combination, impede the ability of elderly persons to accomplish daily tasks in complex life situations (Paillard-Borg et al., 2009; Fei et al., 2009). One of the main determining factors of participation is the ability to be mobile in the community (Anaby et al., 2009). Functional mobility in the community most often includes the ability to walk and perform an additional task, while adapting to changes in the environment (Kizony, Levin, Hughey, Perez, & Fung, 2010), changes in task complexity, and changes in one's abilities such as decreased gait speed or decreased ability to divide attention that occurs during the aging process (Montero-Odasso et al., 2017).

Recent literature suggests that the use of assessment strategies that focus on body function and/or activity (i.e., isolated tasks) rather than on participation (i.e., complex functional tasks) do not take into account all of the factors that contribute to and detract from successful functioning as a person ages (Dawson & Marcotte, 2017). Virtual environments (VE) provide an ecological-valid context to evaluate the domains involved in performance of a complex task (Rizzo & Kim, 2005).

The purpose of this study was to compare gait performance and aerobic effort of young and community dwelling older adults during a complex daily activity in a real mall environment to performance in an identical virtual mall.

2. METHODS

2.1 Participants

Seventeen young (26.8±3.7 years) and 16 older healthy adults (71.2±5.6 years) participated in the study. Comfortable gait speed of the young group was 1.5±0.2 m/s and of the older group 1.4±0.3 m/s.

2.2 Protocol

Participants performed the Multiple Errand Test (MET) in virtual and real world (RW) environments. The MET (Alderman et al, 2003) assesses performance of a complex functional task. The participant is asked to perform several types of tasks such as purchasing specified items and obtaining information (e.g., finding out when the bank is open on a given day). They need to follow rules such as not buying more than two items in the same store and not spending more than a predetermined amount of money. The real-world environment was a small shopping area of about 15 stores all located on the same floor of a building at the Sheba Medical Center, Tel Hashomer, Israel. A virtual rendition of the MET (VMET) was created within the CARENTM (Computer Assisted Rehabilitation Environment) Integrated Reality System to simulate the real shopping mall. The participant viewed the virtual mall projected onto a flat 52" wall-mounted monitor while walking on an interactive, self-paced instrumented treadmill (VGait; Motek Medical B.V.), navigation within the VE was done with a joystick. Data collection was performed at the Center of Advanced Technologies in Rehabilitation at the Sheba Medical Center. The setup is shown in Fig.1. detailed description of the protocol is presented in Kizony et al., (2017).

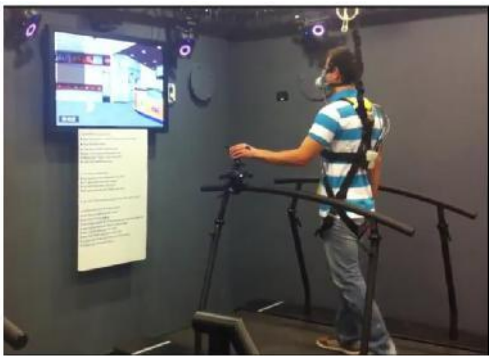

Figure 1. A *screen shot of the simulation's set up.*

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

In addition, in the VE twenty passive markers were placed on the participant's anatomical landmarks based on the Plug-in-Gait model of VICON (C7, T10, Sternum, clavicle, shoulders, 4 on the pelvis; anterior and posterior superior iliac spine, and 4 on each foot; toe, 5th metatarsus, ankle and heel) and detected by 12 VICON infra-red cameras (www.vicon.com).

Heart rate (HR) was measured with a Polar heart rate monitor (https://www.polar.com/en) strapped around the chest. Perceived exertion was measured by Borg's scale, rated from 6 (minimal effort) to 20 (maximal effort) (Carvalho et al., 2009).

2.3 Data analysis

Gait parameters and heart rate were analysed using designated MATLAB scripts (The MathWorks, Natick, MA) (See Kizony et al., 2017 for a detailed description).

Data were analysed using SPSS version 21 (IBM Corporation, Armonk, NY). ANOVA Repeated measures mixed model was used to test differences between environments (within factor) and groups (between factor) as well an interaction effect.

3. RESULTS

The results for the gait parameters are presented in Table 1. Significant differences between environments were found in all gait and aerobic variables. Gait speed and HR were higher in the RW environment whereas perceived exertion of the older group was higher within the VE. In addition, gait variability was higher in the VE.

Table 1. *Gait and aerobic variables according to groups and environments.*

	Young (n=17) (mean ± SD) VE	Young (n=17) (mean ± SD) RW	Older (n=16) (mean ± SD) VE	Older (n=16) (mean ± SD) RW	F environment (1,33)	F age, (1,33)	F interaction (1,33)
Gait speed (m/s)	0.5±0.1	1.2±0.3	0.5±0.2	1.2±0.3	162.6**	NS	NS
Stride length (m)	0.7±0.2	1.3±0.3	0.7±0.2	1.3±0.4	91.6**	NS	NS
Stride time (s)	1.5±0.2	1.1±0.1	1.4±0.2	1.1±0.1	129.5**	NS	5.5*
Stride length variability (CoV)	0.2±0.1	0.1±0.04	0.3±0.1	0.1±0.1	102.1**	NS	NS
Stride time (CoV)	0.1±0.02	0.1±0.01	0.1±0.03	0.1±0.02	35.8**	NS	NS
Heart rate (bpm)	87.3±13.6	95.2±13.8	80.5±12.9	85.6±12.5	12.9**	NS	NS
Borg (score)	10.5±2.4	10±2.1	9.8±2.5	7.9±1.5	14.3**	NS	NS

* P< 0,05; **p<0.01 VE=virtual environment; RW=real world; CoV= coefficient of variance.

4. CONCLUSIONS

The focus of this study was on the locomotion aspect of complex task performance. The results point to the differences between real and virtual environments with regard to gait characteristics and aerobic effort. Performance in the real environment involved higher motor effort than within the VE, regardless of age.

These results raise the question regarding the similarities between real and virtual environments. Whereas similarities between VE and real world performance were found in the cognitive aspects (e.g. Rand et al.,2009), differences in the motor aspect of the upper extremity were found (e.g. Magdalon et al., 2011) which support the current findings. Relative to cognitive tasks, replicating the demands of motor performance in virtual environments appears to be much more difficult to achieve due to differences in locomotion (treadmill vs. overground) and interactivity (pointing vs. touching). Hence the future design of VEs for rehabilitation should make an effort to increase the resemblance between the motor demands of VEs to those of the real world.

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Virtual reality reaching exercise to predict upper limb motor impairment

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ABSTRACT

Chronic upper limb impairment is often caused by central or peripheral nerve damage. Patients undergo a series of assessments prior, during and following treatment. Treatments can range from physiotherapy to surgical intervention, however, assessments are often limited to a small range of tests, including subjective ratings and movement imitation tests. In this study we propose a novel virtual reality based upper limb target reaching assessment with the aim to quantify and predict motor impairment. To limit impairment variability, we artificially recreated a common movement impairment in healthy participants by electrically stiffening the biceps muscle during a point-to-point reaching exercise in a 3D immersive virtual environment. Although our statistical analysis showed no significance between impairment and control conditions, we were able to reliably predict the impairment group with a machine learning algorithm, with 70.1 percent accuracy.

1. INTRODUCTION

Upper limb impairment following central or peripheral nerve injury is characterised by outpatient clinical assessments and through questionnaires. However, these approaches often lack consistency (Platz et al., 2016), with around a ten percent inter-clinician variability in outcome scores, and suffer from subjective bias on both the patient and healthcare side (Gil-Agudo et al., 2013).

Therefore, it is necessary to focus on more data-driven approaches for patient assessments, such as robotics and motion analysis (H. I. Krebs et al., 2007; H. Krebs, Palazzolo, Dipietro, Ferraro, & Krol, 2003). These approaches often utilise robotic equipment and motion detection sensors to capture hand and arm movements during reaching exercises.

Although these techniques are well established, the resultant approaches have yet to be applied in a wider clinical setting (H. Krebs, Krams, Agrafiotis, & DiBernardo, 2014). In addition, evaluation of specific quantified measures of upper limb performance with robotic devices, are limited, mainly due to a lack of robotic expertise in the clinical field, lack of funds to acquire and maintain robotic equipment and a standardised clinical setup.

To address these issues, in this study we introduce a 3D virtual reality (VR) point-reaching exercise, to emulate pointing/reaching to objects in activities of daily living (ADLs) tasks, e.g. reaching to a glass of water. We used widely accessible off-the-shelf VR equipment and a set of seven kinematic measures of performance, such as hand velocity and end-point accuracy. To focus on a narrow range of upper limb movement impairments, we only recruited healthy participants and used electrical muscle stimulation (ES) to simulate increased biceps muscle stiffness, as experienced by some patients (e.g. chronic upper limb spasticity/stiffness following stroke) during movement. We hypothesise that kinematic measures provided in this fashion would allow us to reliably predict movement impairment.

2. METHODS

2.1 Participants

We recruited 16 right handed, healthy participants from a student population, 5 of which were excluded from this study due to a technical issue with the setup (6 females, = 24 SD = 4). All participants had normal to corrected vision and none reported prior upper limb injury or related neurological deficits.

2.2 Equipment and setup

The Oculus rift CV1 (Oculus, Facebook, SD, USA) system (headset and Oculus Touch controllers) produced the visual scene via the Unity3D game engine (Unity 2017.3.0f3, 2017, Unity Technologies SF, San Francisco, California, USA), including real-time positional feedback of head and hand tracking at 120Hz. A secondary, ground-truth ProReflex 240 Qualisys (Qualisys AB, Goeteborg, Sweden) optical motion capture system was used to also capture upper arm, shoulder and forearm motions at 120Hz, see Appendix 8. The motion data from the

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ground-truth motion capture system is not included in this study, but it allowed us to qualitatively validate the Oculus tracking system. The experiment was executed via a virtual reality (VR) ready windows 8.1 computer.

2.2.1 Muscle stimulation.

Two pairs of single-patient surface electrodes were applied to the Biceps and Triceps muscles of the right arm, fixed in place using an elastic strap. ES was provided by a Digitimer DS7A current stimulator (Digitimer, Hertfordshire, UK), and a Raspberry Pi computer (Raspberry Pi Foundation, Cambridge, UK) was used to control the stimulation parameters via a network User Datagram Protocol (UDP) with the host VR computer. The total ES stimulation duration was set to 250ms with the initial increasing and final decreasing ramps of 50ms. Further stimulation parameters were set at a 1000µs pulse width, 300V and the stimulation current was individually adjusted to create an approximately 30 degree arm deviation from a relaxed, hanging arm pose, with current ranging from: 0.5mA to 1.5 mA. ES was triggered and maintained from the initiation of movement until the participant hit the target.

2.3 Design and Protocol

The experiment used a repeated-measures design with three randomly interleaved conditions. On a single trial, participants either received ES to the Biceps (Condition 1), Triceps (Condition 2) or no ES (Control). From a total of 560 trials, 280 trials were assigned to the control condition and 140 trials each for Biceps or Triceps stimulation conditions. This 2-to-1 ratio of control to stimulation conditions and the addition of a second stimulation condition (Triceps) made it more difficult for participants to predict Biceps ES trials. The Triceps condition was not considered in the analysis. A single target (20cm high by 10cm wide octahedron object) randomly appeared at one of seven predefined locations on a clock like circle that covered the available visual field (100^o horizontal and 80^o degrees vertical), calibrated at arm's length, Figure 1. Participants were instructed to aim and reach to the targets as fast and as accurately as possible. We were able to counteract compensatory movements by maintaining the relative positions of the targets to the participant, because we provided a fixed starting point (3L cube) relative to the head and hand positions at calibration. The researcher instructed a 30 seconds rest period every 70 trials to avoid muscle fatigue and the entire study lasted around an hour, including debriefing time.

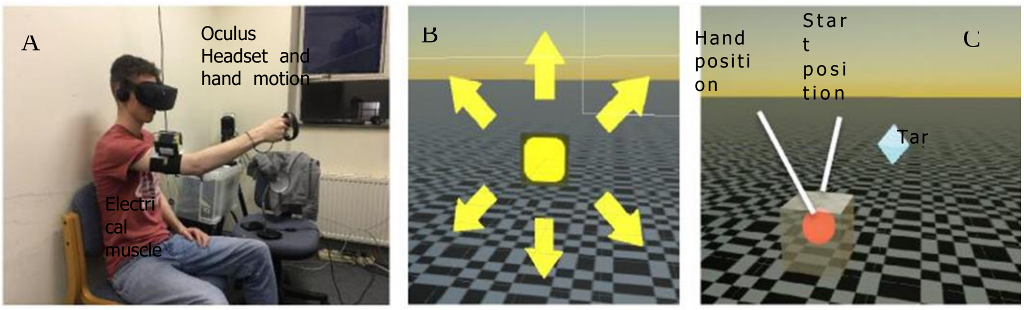

Figure 1. A: *Experimental setup; B: Calibrated target locations; C: Participant view in VR.*

2.4 Audio-Visual Feedback

To maintain engagement and motivation throughout the reaching task we provided a trial based performance score and a total score that accumulated throughout the exercise. The feedback was parameterised to three relative levels of feedback (good, average and bad) depending on average movement speed and end-point reaching accuracy. The scores were matched to the participant's initial performance on 30 trials in the familiarisation run.

2.5 Data Analysis

We analysed the data using two different approaches, (1) repeated-measure ANOVA to compare control and impairment conditions using seven kinematic parameters, which are average, total and maximum path offset, positional end-point error, path length, average and maximum tangential velocities, (2) machine learning with a feed-forward neural network using the same seven kinematic parameters as input, Figure 2.

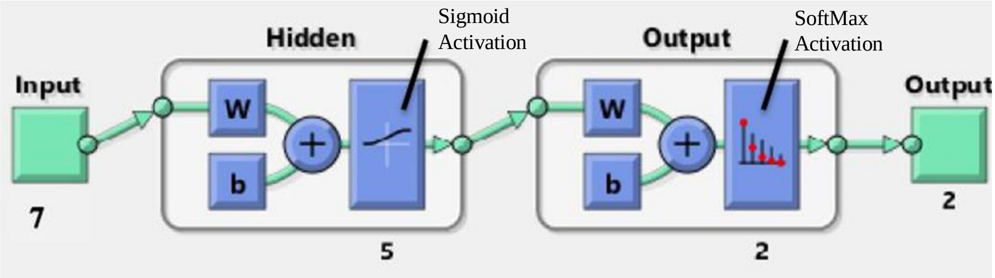

Figure 2. *Network architecture with one input layer, 5 unit hidden layer and two output units in the output layer.*

2.5.1 Neural network architecture.

We used a fully connected feed-forward neural network, with one 5 unit hidden layer and two output units. The numbers of input layer units were fixed to seven. A sigmoid activation function connected the input to the hidden layer and a SoftMax activation function connected the hidden to the output layer. These choices of activation functions are commonly used for classification problems, such as in our case. The weights (w) and biases (b) were initialised randomly using Xavier initialisation before the start of training (Glorot & Bengio, 2010).

2.5.2 Training.

We trained the network using batch training with a batch size of 35 and stopped after 2000 epochs. Results are averaged based on 10 repeats of this process. To get a better estimate of the performance, we presented a randomly shuffled data set each trial, preserving 28% of the full data set for testing.

3. RESULTS

3.1 Raw analysis

We extracted seven kinematic measures of performance from the raw movement trajectories (Figure 3A). Figure 3B was created from all 280 control and 140 biceps stimulation trials from one example participant. The trajectories have been overlaid to qualitatively highlight areas of overlap and divergence between both conditions.

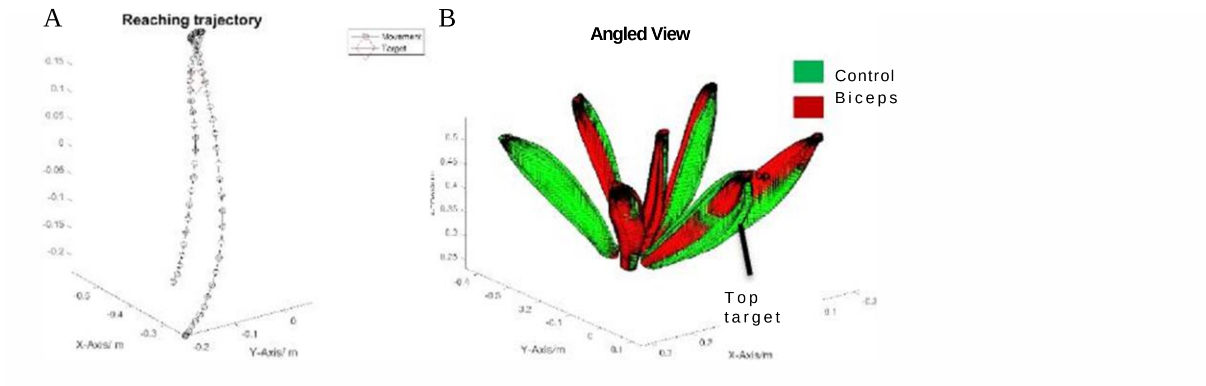

Figure 3. A: *Reaching trajectory from a single example trial; B: All 420 trajectories from both ES and control conditions.*

Figure 4 shows a normalised version of these kinematic measures for each of the seven targets from an example participant. The raw version of this pattern of information was used both in our statistical analysis and as input to our neural network.

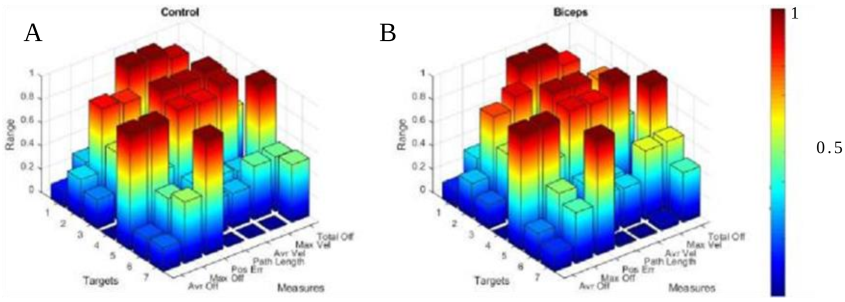

Figure 4. A: *Normalised average kinematic measures for the control (280 trails) and biceps (140 trials) (B) conditions. This example figure comes from participant 4 and is for illustrative purposes only.*

3.2 Statistical analysis and machine learning results

The repeated-measures ANOVA did not show any significant differences between the control and biceps stimulation conditions, see Appendix 1-7. However, our machine learning results showed an average (n=10) of 78.2 percent prediction accuracy in the training and 70.1 percent in the testing set, i.e. validation on a new group of subjects.

4. CONCLUSIONS

In this study we briefly described the need for a robust and easily accessible system for upper limb functional assessment following nerve injury. To answer this need we proposed the use of off-the-shelf VR equipment (Oculus rift) and a point-reaching task in a 3D immersive virtual environment.

Although our extracted kinematic measures proved reliable in predicting artificially induced upper limb impairment, this approach may not translate to patients. To make our predictions relevant to patient assessments we would require a database of kinematic patient measures and be able to correlate these with clinical data, such as Fugl-Meyer scores or the Barthel Index. The machine-learning algorithm can then be retrained with patient data to classify new patients into predefined impairment groups.

Finally, motivation during the hour long task is an important factor but often neglected by similar studies (Lucca, Candelieri, & Pignolo, 2010; Shirzad & Van der Loos, 2013). Although we attempted to address this issue by providing audio-visual feedback during the task, we did not look at the effects of motivation in a structured manner. In a follow-up study we aim to answer the following questions: Is the level of motivation an important predictor of performance, and can we relate low motivation to the dropout rate often encountered in similar longitudinal studies?

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6. APPENDIX

1. Total Offset

Source	SS	df	MS	F	p
Conditions	0.1421804	1	0.14218049	0.27202924	0.614564367
Targets	229.68534	6	38.2808914	19.5594448	5.66636E-12
Conditions x Targets	1.6316410	6	0.27194017	1.49731183	0.196697785
Conditions x Subj	4.7039960	9	0.52266622		
Targets x Subj	105.68644	54	1.95715633		
Conditions x Targets x Subj	9.8074222	54	0.18161893		

2. Average Offset

Source	SS	df	MS	F	p
Conditions	0.0022746	1	0.00227466	1.13308780	0.314841651
Targets	0.2146039	6	0.03576732	17.3289464	4.7222E-11
Conditions x Targets	0.0111378	6	0.00185630	0.91599447	0.490702105
Conditions x Subj	0.0180673	9	0.00200748		
Targets x Subj	0.1114571	54	0.00206402		
Conditions x Targets x Subj	0.1094334	54	0.00202654		

3. Max Offset

Source	SS	df	MS	F	p
Conditions	0.0037916	1	0.00379169	1.66702363	0.228832926
Targets	0.1907861	6	0.03179768	10.6473504	8.86996E-08
Conditions x Targets	0.0110839	6	0.00184732	0.82753132	0.553783926
Conditions x Subj	0.0204707	9	0.00227452		
Targets x Subj	0.16126782	54	0.00298644		
Conditions x Targets x Subj	0.1205462	54	0.00223233		

4. Max Speed

Source	SS	df	MS	F	p
Conditions	0.17557248	1	0.17557248	0.49326943	0.500232185
Targets	15.9472237	6	2.65787062	12.3476822	1.06575E-08
Conditions x Targets	0.87210548	6	0.14535091	0.66186582	0.680553178
Conditions x Subj	3.20342647	9	0.355936274		
Targets x Subj	11.62364004	54	0.215252593		
Conditions x Targets x Subj	11.85882244	54	0.219607823		

5. Average Speed

Source	SS	df	MS	F	p
Conditions	0.009159876	1	0.009159876	0.6390148	0.444652145
Targets	3.158427511	6	0.526404585	29.088551	2.88658E-15
Conditions x Targets	0.042174507	6	0.007029084	0.9310546	0.480393944
Conditions x Subj	0.129009332	9	0.01433437		
Targets x Subj	0.977217709	54	0.018096624		
Conditions x Targets x Subj	0.407678056	54	0.007549594		

6. Path Length

Source	SS	df	MS	F	p
Conditions	0.001588583	1	0.001588583	0.5823690	0.464917401
Targets	0.578926288	6	0.096487715	29.070591	2.9976E-15
Conditions x Targets	0.008029635	6	0.001338272	0.8856771	0.511848616
Conditions x Subj	0.024550144	9	0.002727794		
Targets x Subj	0.179230497	54	0.003319083		
Conditions x Targets x Subj	0.08159487	54	0.001511016		

7. Positional Error

Source	SS	df	MS	F	p
Conditions	0.000334614	1	0.000334614	1.502254	0.25142929
Targets	0.014455376	6	0.002409229	1.338298	0.25646653
Conditions x Targets	0.001785864	6	0.000297644	1.318707	0.26482450
Conditions x Subj	0.002004669	9	0.000222741		
Targets x Subj	0.0972118	54	0.001800219		
Conditions x Targets x Subj	0.012188279	54	0.000225709		

8. Ground-truth motion capture

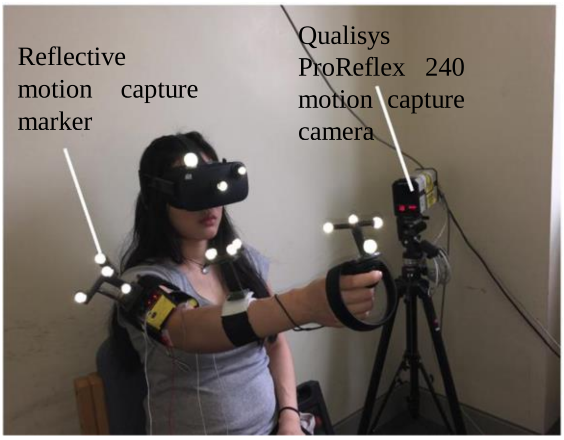

Figure Appendix 8. *Virtual reality target reaching exercise experimental setup with optical ground-truth motion capture system*

Towards effective cognitive rehabilitation in embodied virtual reality: Designing for executive dysfunction

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ABSTRACT

Virtual reality technologies are being developed in service of many rehabilitation activities. One of particular interest is the cognitive assessment and therapy of people with executive dysfunction (ED) arising from acquired brain injuries (ABIs). Socio-cognitive regulation of behaviour is a major challenge faced by ED rehabilitation professionals. An effective approach to the creation of a virtual rehabilitation environment must be theoretically sound and practicable for therapeutic use. In this paper, we report our user-centred design research using a clinically established framework to deliver meaningful therapeutic activities in an embodied virtual reality multiple errands test (EVR-MET). Our design work focuses on support for three-way interactions between service users, clinicians and the semi-autonomous virtual characters under their control. Our preliminary evaluation work with end users suggests that this approach is capable of drawing out the unique challenges they each face.

1. INTRODUCTION

An estimated 350,000 people are affected in the UK each year by an acquired brain injury (ABI), which may occur through trauma, degenerative condition, or other causes (Headway, 2018). ABIs frequently affect frontal lobe areas associated with both higher cognitive functioning and a variety of social competences. Taken together, these impairments of 'executive function' impact on the group of cognitive processes responsible for monitoring and regulating behaviour. People so affected tend to be at high risk of putting themselves in difficult social and physical situations and, as a result, require high levels of support and supervision. In this paper, we report our research towards developing a clinically valid approach to virtual reality interaction design for socio-cognitive rehabilitation activities. We first discuss the special nature of the design challenge for rehabilitation of frontal ABIs, review the literature and the clinically motivated framework for design, before describing our implementation work to date (EVR-MET). We conclude by outlining the control challenge for semi-autonomous three-way interactions in the environment.

2. DESIGNING TO SUPPORT COGNITIVE REHABILITATION PRACTICES

Virtual reality technologies have been employed to support the recovery of people with physical injuries and psychological conditions (Jacoby et al, 2013) and also to assess executive functioning (Davison et al, 2018). They offer a fine level of control over the physical load to be handled by individuals, with helpful feedback and guidance, together with repeatability that can be difficult or expensive to achieve in corresponding physical settings. However, relatively little research has looked at the potential of synthetic environments to assist with social-cognitive rehabilitation. That is, the construction of a virtual environment that simultaneously tax a person's ability to maintain appropriate social interaction with other agents, while managing the planning and execution of information- or knowledge-centric activities.

Termed executive dysfunction (ED), the set of cognitive impairments that affect a person recovering from an ABI presents a complex range of rehabilitation challenges. Even seemingly basic everyday tasks, such as buying a bus ticket, require the coordination of many cognitive abilities and social awareness that are impacted by ED. They come together to limit a person's ability to deal with frustrations, temptations and distractions. The rehabilitation of executive dysfunction is seen as a key predictor of successful reintegration into the community following an ABI (Sohlberg and Mateer, 2001). Challenging behaviours are common amongst those living with ED and are associated with strong impulsivity manifesting as physical, emotional and social responses to situations. The assessment and training activities necessary for effective rehabilitation typically couple the prosecution of mutually constraining tasks (managing multiple goals) within a regular social environment.

Consider for example the socio-cognitive work required to obtain items on a shopping list from relevant vendors before they close for the day. Real-world shopping requires thought about location and availability of items and re-planning. It also requires patience, persistence and politeness in social encounters that vary despite their routinized nature. This latter challenge is often the most demanding for people living with ABIs, because their atypical mannerisms tend to colour the attitude of members of the public towards them. Consequently, they may well have to deal with suspicion and rudeness much more commonly than a neurotypical person. The practical consequence of this for ED rehabilitation is that 'real world' exposure for assessment and training requires very significant supervision, planning and a high degree of uncertainty about the clinical value of the activity on any given occasion.

Virtual reality has the potential to address these rehabilitation challenges, supporting the construction of meaningful socio-cognitive exercises, provided interactions can be designed and regulated such that they respect the practices health professionals have developed for addressing the very challenging nature of executive dysfunction.

3. EXECUTIVE FUNCTIONING: PRINCIPLED ASSESSMENT AND TRAINING

The rehabilitation of executive dysfunction brings together teams with diverse backgrounds and highly specialised skillsets. Executive dysfunction, as an umbrella term for deficits in the processes that regulate behaviour, is such a broad diagnosis that tackling it must surely be an insurmountable challenge for even the most experienced of clinicians. For the rehabilitation of ED to be successful, a framework must be utilised to identify specific aspects of behaviour that are impaired and require therapeutic intervention.

Frontal brain injuries cut across the regulation of behaviour and are difficult to categorise into discrete components (Purdy, 2011). Conceptual models of brain functioning have been developed to support clinical professionals' approach to any given service user's behaviour as the sum of executive operation, linking behaviour to executive functioning. The approach described in this paper has been developed over three years in close association with clinical neuropsychologists and rehabilitation professionals at the Brain Injury Rehabilitation Trust. Sohlberg and Mateer's (2001, p.236) Clinical Model of Executive Functions (CMEF) provides a framework for our approach, resolving on six complementary elements of executive functioning as a tractable and theoretically grounded set for guiding rehabilitation work. They are initiation and drive, response inhibition, task persistence, organisation and planning, generative thinking, and awareness (see Table 1). Together, they capture important everyday aspects of difficulty in managing multiple goals and also in routine social communication. The Multiple Errands Test (MET) is commonly used as a clinical tool for both assessment and training in ED (Shallice and Burgess, 1991; Josman et al, 2006; Rand et al, 2009; Jacoby et al 2013; Davison et al, 2018). The test combines a list of things to be done with a set of constraints on doing them, such as the order or preconditions to observe. Table 1 shows how aspects of the CMEF might be evident in behaviours observed as a service user attempts the MET.

It is important to understand that our approach is integrative: describing executive dysfunction in terms of individual components is not enough. The cross-cutting regulatory nature of executive function requires the generation of opportunities for behaviours to be enacted that span them, as guided aspects of mental engagement with socio-cognitively meaningful activities. Isolated behaviours may not immediately reveal how an aspect of executive functioning is compromised, or even whether multiple aspects of impairment interplay. Service users must perform complex task sequences while maintaining appropriate social interaction with other agents, if their specific impairments are to be drawn out and targeted.

Table 1. *Aspects of ED mapped to MET and EVR-MET. Adapted from Sohlberg and Mateer (2001, p. 236).*

Domain of executive function model	ED applied to MET	ED applied to EVR-MET
Initiation and drive	Does not attempt tasks	Does not attempt one or more of the virtual tasks; does notinitiate conversation with the character
Response inhibition	Does not refrain from undesired activities; completes tasks even if breaking other tasks; breaks rules	Inappropriately comments about character; violates constraints of the tasks; attempts to touch the character
Task persistence	Does not maintain attention on the exercise; has poor working memory of the tasks	Does not return to the task if led astray by the character; gives up when the character is unhelpful; forgets answers and completes tasks multiple times.
Organisation	Has poor goal identification; is not aware of or keeps track of time; does not plan out tasks; does not keep track of performance	Struggles to convey meaning in conversation with the character; does not plan out virtual tasks
Generative thinking	Cannot switch between tasks; does not know which shops to go to; cannot generate novel	Gets stuck on a task and cannot move on; cannot generate solutions to tasks; cannot respond to open-ended questions from the character; cannot re-plan if information is not available

Awareness	Does not use compensatory strategies to overcome deficits (e.g. referring to paper); demonstrates poor insight on performance	Does not recognize setbacks;is not aware of deficits in communication; poor insight on performance (believes it to be good even if no tasks completed)

Clinical practice requires that therapeutic activities are closely tailored to adjust the challenge faced by service users. Importantly for rehabilitation, this fosters the growth of 'insight' and focuses treatment. We are committed to an approach that supports dialogue between clinicians and service users, via an unfolding socio-cognitively meaningful scenario in a virtual world. We consider this to be essential for the validity of our work.

4. DESIGNING THE EVR-MET

We have developed an immersive and interactive virtual environment that places ABI service users into a Multiple Errands Test-inspired scenario that challenges their ability to perform non-routine tasks. Importantly, the experience takes place in embodied virtual reality, such that they can interact with the world in not only an intuitive manner – turning their head, carrying a task list, speaking to communicate – but using ecologically familiar skills. In the context of assessment, we propose this as advantageous to both service user and clinician, as behaviour exhibited in embodied virtual reality – asking a question to someone, getting irritated at the response – may map to behaviour exhibited in the real world. Relevant behaviours in ecologically valid settings may then be observed from the safe and controlled space of a clinical rehabilitation unit.

The Embodied Virtual Reality Multiple Errands Test (EVR-MET) draws upon some of the basic principles of Shallice and Burgess' (1991) MET. When the user puts on the VR headset, they are seated or standing in a UK-based street. They are asked to perform a series of tasks involving finding out information, all of which can be found in the immediate area (Figure 1). The assessment involves the organisation of tasks and generative thinking to find the relevant answers. There are also opportunities for clinicians to observe communication within the environment; some information can only be acquired by asking a virtual character.

Figure 1. *A virtual character on a street in the EVR-MET (left) and the headset view (right).*

The development of the environment was based on user centred design principles, with close engagement with clinical professionals. Detailed evaluation of the performance on the environment was then carried out with 14 neuro-typical volunteers with no significant experience of VR game environments. To date three brain injury service users have experienced the EVR-MET. These users, who were under the supervision of a clinician, presented with a range of ED impairments that affected their socio-cognitive abilities. Our early results indicate that the ED difficulties faced by each individual were starkly highlighted through their engagement with the EVR-MET, and support the use of clinician-driven characters as a mechanism to control and deliver socio-cognitive challenges. The next step in the work will be to obtain quantitative and qualitative information from users with ED and clinicians employing this tool to allow comparison of efficacy of clinician versus VR delivered therapy.

5. CONCLUSIONS

To be effective for people living with executive dysfunction, rehabilitation exercises should combine social encounters with cognitively challenging activities. We have argued that the cross-cutting impairment of EF arising from frontal ABIs identify special value in the potential of VR. To fully realise this, VR environments should be designed to expose important behavioural correlates of ED, guided by theoretically valid models such as the CMEF, and so that rehabilitation professionals are able to participate in and control ecologically integrated socio-cognitive activities with their service users. Further research is required to understand how the three-way dynamic of clinician/VR character/service user can be optimised to suit particular rehabilitation goals.

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Towards valence detection from EMG for virtual reality applications

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ABSTRACT

The current practical restraints for facial expression recognition in Virtual Reality (VR) led to the development of a novel wearable interface called *Faceteq*. Our team designed a pilot feasibility study to explore the effect of spontaneous facial expressions on eight EMG sensors, incorporated on the Faceteq interface. Thirty-four participants took part in the study where they watched a sequence of video stimuli while self-rating their emotional state. After a specifically designed signal pre-processing, we aimed to classify the responses into three classes (negative, neutral, positive). A C-SVM classifier was cross-validated for each participant, reaching an out-of-sample average accuracy of 82.5%. These preliminary results have encouraged us to enlarge our dataset and incorporate data from different physiological signals to achieve automatic detection of combined arousal and valence states for VR applications.

1. INTRODUCTION

Multiple computational systems and interfaces are available to enhance Human Computer Interaction (HCI). For emotion recognition, various methods are currently under investigation to assess human affective states and expressions (see review by Calvo & D'Mello, 2010). Typically, emotions are measured in a two-dimensional space consisting of their arousal (activation or excitement levels) and valence (positive/ negative polarity levels) which are considered as the basic quantitative dimensions of emotions (dimensional model by Russel, 1980). Multiple studies have explored the link between self-rated levels of arousal and valence, and physiological and/or behavioural changes, and their classification for HCI applications (e.g. Healey & Picard, 2005). Although, researchers in interactive technologies tend to focus on the identification of arousal through physiological measures (e.g. Wu et al, 2010; Yannakakis & Paiva, 2014), we believe that the coalescence of both dimensions is required to evaluate the nature of the emotion elicited during an immersive experience. The majority of research in valence detection emphasises the interpretation and analysis of facial expressions; either via computer vision (see Zeng et al. 2009 review) or facial EMG signals (e.g. Fridlund & Cacioppo, 1986; Cheng & Liu, 2008). The majority of these measures are today often combined for multimodal affective and physiological computing.

Commercial low-cost first and second generation Virtual Reality (VR)technologies became largely available after 2014 (with the introduction of Oculus Rift DK2), enabling a larger number of researchers to investigate user-experience effects in VR. VR provides a platform for the design of controlled experimental conditions while granting ecological validity and an abundance of content resources. Research from diverse disciplines gradually adapt VR for their experimental designs and executions (e.g. Bekele et al, 2007; Yang et al,2017; Burke, 2018). As the number of VR-related projects is increasing, emotion detection in VR is anticipated to become a vital piece for future research. The study of emotion elicitation and detection in VR however is still in its infancy (Diemer et al, 2015). Research in VR often combines different measures such as behavioural observations and physiological measures as e.g. heart-rate and galvanic skin response (Slater et al, 2006; Giakoumis et al, 2009) to report arousal levels; although emotion-related studies in VR such as Riva et al (2007) often utilise questionnaires to identify psychological states and valence levels. The area of the face which is rich with valence information is usually left unexplored since the Head-Mounted Display (HMD; commonly used for immersive VR) is covering almost 2/3 of the face, including the most informative facial muscles. As VR technologies are improving and their uses are increasing, it is fundamental to propose alternative, novel approaches to measure emotions. This will enable a better understanding of the emotional states induced in VR and the latter's effect on human feelings and elicited responses.

In 2016, we proposed a novel hardware solution, 'Faceteq', for facial muscle activation monitoring (Mavridou et al, 2016) in VR. Faceteq was designed to work as an extra intermediate layer between the HMD and the face of the wearer, consisting of eight electromyography (EMG) sensors, two Photoplethysmogram sensors (PPG) and one inertial measurement unit (IMU) including gyroscope and accelerometer. We hypothesise that such an interface can track the valence information needed for continuous emotion assessment in VR. To our current best knowledge, this is the first study where integrated surface EMG sensors have been used for valence detection in VR. Therefore, we investigated the feasibility of this approach in controlled conditions, using audiovisual stimuli on a monitor. This feasibility study has been specifically designed to induce three valence levels to test the sensitivity of the metrics derived from the wearable sensors (EMG, PPG, IMU) employed on the Faceteq interface. For the purpose of this paper, we included only the surface EMG data and valence ratings in our analysis.

2. EXPERIMENT SET-UP

2.1 Stimuli

A selection of the videos with affective content from the affective film library by Samson et al. (2016) was used for this study. The selection of videos was intended to elicit two levels of valence and two levels of arousal, in order to obtain physiological responses for each of the 4 quadrants of the dimensional model. For this reason, 5 videos per category (four categories) with the highest and lowest rating of valence and arousal were selected, as well as 20 neutral videos. The order of videos categories was counterbalanced across participants and presented as follows: five affective videos from one category, followed by five neutral videos, followed by five affective videos from another category etc. Each video had a fixed duration of 25 seconds. Grey images were added after every video for 8 seconds each. The video order within a category was newly randomised for each participant.

2.2 Participants

For this preliminary study, 35 participants were recruited (20 female), from 18 to 40 years old (M: 22.8, SD: 5.2). Participants were told that we were monitoring the electrical conductivity of their skin and were instructed how to rate their felt emotions in terms of arousal and valence prior the video presentation. Questionnaires verified that the participants were not suffering from anxiety, depression or any disorder that can affect their facial movements at the time that the study took place.

Figure 1. *Video presentation environment*

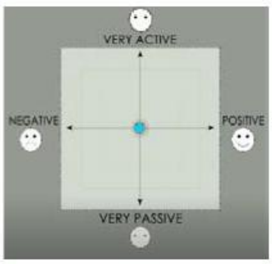

Figure 2. *CASR interface*

Figure 3. *Faceteq interface*

2.3 Apparatus

The stimuli presentation. We designed and developed an application with three environments/scenes: (1) a training environment where we asked participants to get familiar with the Continuous Affect Self-rating (CASR) interface (based on the *'FeelTrace'* tool for affect rating; Cowie et al, 2000) (Figure 1 & 2), (2) a grey scene where the participant were asked to relax while we recorded neutral (baseline) data, and (3) a semi-dark cinema environment where the videos were presented next to the CASR interface which was placed on the bottom right corner of the screen (Figure 1). The participants were requested to face the monitor and perform minimum head movements during the recording.

Monitoring Equipment and sensors.

The interface prototype was equipped with eight surface dry electromyography (f-EMG) sensors on the right and the left side of the face (Channels; 1 & 2 on Zygomaticus major, 3 & 4 on Frontalis, 5 & 6 on Orbitocularis oculi and 7 & 8 Corrugator muscles) using an adapted protocol described by van Boxtel (2010).

2.4 Experiment procedure

The study took approximately 50-60 minutes and was conducted at our laboratory at Innovation Centre at Sussex University. During the study, each participant watched a randomised sequence of movie clips for approx. 22 mins. During this time, they were asked to rate their felt emotions using the CASR interface. During the video presentation, video capture of the participant's face and physiological responses were recorded. All sensor data streams were synchronised with the video presentation via the Faceteq API to ensure ease in analysis and efficient event detection. Each participant was compensated by a £5 voucher for their time. The study was reviewed and approved by the Science, Technology & Health Research Ethics Panel, Bournemouth University (Ref. 13994 on 26/01/2017).

3. DATA ANALYSIS

EMG recordings from 8 channels were recorded using Faceteq API (sampling rate: 1000Hz) and afterwards analysed offline in Matlab. Firstly, a baseline correction was applied, by subtracting the mean EMG values. We then removed 50Hz and their harmonics up to 350Hz using Notch filters. The signals were band-pass filtered from 30 to 450 Hz. Extreme outliers caused by motion artefacts were removed using a Hampel filter. Next, the EMG recordings from the 8 channels were divided in epochs of 22 seconds which is corresponding to the video duration minus the first 3 seconds of each video. Next, the Root-Mean Square value per 512 samples window was calculated. As EMG are highly variable between wearers, and since we are interested in detecting valence states (negative, neutral, positive) we applied a Maximum-Minimum normalization function. The data were used as input to train a C-Support Vector Machine (SVM), using the libSVM (Chang & Lin, 2011). For each video and for each participant from the data set, the ground truth was defined by the corresponding participant's CASR valence-only scores. The data and labels were sent into an SVM (RBF kernel) for classification, using 10-fold cross validation for each participant separately. The low computational cost of the implementation enabled the approach to provide a cross-validated readout in less than 0.5 seconds per participant.

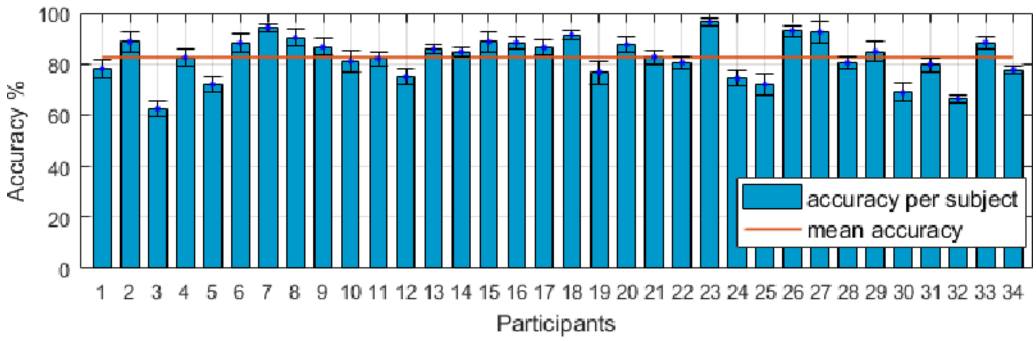

Figure 4. *Classification accuracies for all 34 participants*

4. RESULTS AND DISCUSSION

Overall, we tested the feasibility of our prototype for valence detection in VR. The C-SVM enables us to map the levels of activation of EMG channels with the spontaneous expressions during the stimuli categories. Each model, trained with data from each of 34 female and male participants achieved an accuracy ranging from 62.4% to 96.4%, with an average accuracy across the group of 82.5% (Std: 8.2) (Figure 4).The results of this initial study confirmed the feasibility of our approach. We are currently analysing the remaining recorded physiological responses related to heart rate, head movement and electrical conductivity of the skin, which are expected to provide further insights, as well as assist on the refinement of our valence and arousal detection for VR applications. We envisage that a larger sample size will enable the system to achieve higher accuracy on valence and arousal detection and a more robust model. This model may be able to discover common facial patterns in clusters of participants, and more fine-grained levels of valence and arousal i.e. additional levels of classes.

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Reflections on the design and development of a virtual reality mirror therapy system for upper limb stroke rehabilitation

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ABSTRACT

As a leading cause of disability, stroke damage in the brain may affect different areas of the body. When upper limb weakness and loss of mobility seriously impede daily living activities, it impacts on quality of life at the cost of independence. A severely impaired limb might respond to mirror therapy (MT) as part of rehabilitation via a mirror box through use of the less affected limb. However, traditional mirror therapy has innate limitations that may be overcome through use of virtual reality (VR) based mirror rehabilitation system. VR can control environmental aesthetics, personalising visual and auditory information appropriate for stroke survivors. VR can embed an automated rehabilitation system which adapts to an individuals' need founded on clinical assessment. Physical interactions can be modelled, and performance monitored by computer and parameters adapted based on individual profiling. Task guidance can be automated, and a range of immediate and summative feedback can be provided. Activities may be embedded into a range of fun games and play-oriented tasks can match clinical objectives and personal goals. VR mirroring can implement several virtual modes otherwise impossible with a traditional mirror box. We discuss these and outline our progress in using a user centred development process to create a VR mirror system which utilises inverse kinematics to animate a complete humanoid avatar with six degrees range of movement to enhance user agency. Our goal is a controllerless system supporting different mirroring modes, in which the user need only wear the headset to access their rehabilitation. Accommodating six degrees of movement is a significant challenge where only a user's head and hands are tracked. However, successful implementation of such a system will enable deployment of mirror therapy to low cost VR hardware and thus be more accessible for home rehabilitation.

1. INTRODUCTION

Strokes occur when blood flow to the brain is disrupted. A disproportionate volume of the motor cortex is dedicated to the hands and so upper arm disability is common after stroke. The resulting impairment can significantly impact a survivor's capability to perform daily living tasks, subsequently reducing quality of life. Key statistics show over three quarters of stroke survivors report arm weakness with fatigue also common (Stroke Association, 2017). In addition to physical impairment, neurological damage is also a consideration as brain injury can result in nerve dysfunction. Restricted mobility, reduced cognitive ability and mood change can also affect physical and mental capacity. Physiotherapy-specific exercises can help stroke survivors regain strength and movement in affected limbs, and functional exercises may help remodel undamaged parts of the brain via neuroplasticity (Helpline, 2012). Emerging evidence suggests MT can be effective in stroke rehabilitation (Thieme *et al.*, 2012), and technologies such as games, virtual reality (VR), and augmented reality are also being increasingly used as the basis for motivating, self-management of rehabilitation. Although there are several studies focussed on traditional MT within the literature, its application within VR is more limited. In this paper, we present an early stage innovative mirror VR system to investigate a range of virtual mirror modes facilitating MT physical movement through six degrees of freedom. Thus, the user can move freely around a virtual environment (VE) with correct mirroring, potentially offering a wider range of interactive tasks.

2. BACKGROUND

Mirror therapy has been investigated since the 1996 publication "Synaesthesia in phantom limbs induced with mirrors" by VS Ramachandran. In the same year Max M. North, Sarah M. North, and Joseph R. Coble published the first VRT book *Virtual Reality Therapy, an Innovative Paradigm*, which looked at the use of VR for stroke survivors, games and haptic controllers to help improve fine motor control. Post-stroke physical recovery requires strengthening muscles and retraining the brain to renew motor movement. Rehabilitation is achieved through intense, repetitive physical exercises targeted on motor recovery utilising the neuroplasticity of the brain to reinforce relevant neural pathways (Weiss, Keshner and Levin, 2016). Repeated practice is a fundamental factor, with the effect being most evident in early stages and reducing over time (Levin, Weiss and Keshner, 2015). Computer-based rehabilitation (Saposnik and Levin, 2011), including VR (Schuster-Amft *et al.*, 2015) can support these goals through guided exercises and informative feedback (Holmes *et al.*, 2016). Rehabilitation can be personalised (Genius *et al.*, 2013) to individual disability and tasks adapted based on tracked capability (Holmes *et al.*, 2016). VR and games can also help motivate people to sustain their treatment and improve engagement with exercise (Levin, Weiss and Keshner, 2015) that they may otherwise find tiring and difficult. Extremely limited mobility in the most affected limb makes it very challenging for stroke survivors to perform even minor rehabilitation tasks without arm support or robotic aids. Such severe impairment limits task availability and presents a difficult design challenge. MT may support motor recovery in such cases and operates on the principle of a mirror illusion; creating a perception the affected limb is moving while it is actually a reflected image of a person's less affected limb. Traditional MT uses a mirror box to achieve this effect (Ramachandran and Rogers-Ramachandran, 1996). Even with a severely disabled limb, the unaffected limb can perform the task (Thieme *et al.*, 2012). MT's influence on cortical and spinal motor excitability may be due to effect on the mirror neuron system and possibly this approach exploits the brain's preference to prioritise visual feedback over somatosensory/proprioceptive feedback relative to limb position. In VR, a person is fully immersed in a virtual world where their environment can be completely controlled. Environmental aesthetics (graphics, audio) and physical qualities (gravity, movement) can be modified to increase feelings of presence in a virtual world and promote a sense of embodiment within an avatar (Jerald, 2016). Unbound by the laws of physics, VR environments may be exploited to enrich feedback or to augment tasks so they better suit rehabilitation goals (Saposnik and Levin, 2011). These VR qualities may enhance the impact of the mirror 'trick' to help motor recovery. VR MT systems have been developed but implementation into clinical practice varies greatly (Shiri *et al.*, 2012; Diers *et al.*, 2015; Schuster-Amft *et al.*, 2015). We may also test several variations of VR MT modes with a virtual avatar, impossible in traditional approaches. We describe these below.

3. SYSTEM DESIGN AND EVALUATION

VR describes (i) reflected illusion area when using a mirror box (Ramachandran and Rogers-Ramachandran, 1996) and (ii) in technological terms VR is achieved by stereoscopic visual display with other peripherals to enhance immersion within the VE. Our goal was to create a VR upper limb mirror rehabilitation system to replicate and potentially enhance traditional mirror box rehabilitation tasks. Secondary objectives were to implement a controllerless system, i.e. upper body movement recognised by sensors, supporting mirroring techniques through six degrees of freedom (6 DoF), i.e. a user orientation and movement tracked through a 3D space (Fig.1a).

Figure 1. a) 6 DoF and Sagittal Mirror plane b) Mirror VR trackers c) Mirror Mode-C in-game with visual trails

A user-centred design methodology with an evolutionary prototyping process was adopted. Table 1 shows the key stages of our development. Evolutionary design and development facilitates iterative improvement of the system through user feedback and system testing after each development stage. Fig. 1a shows the initial animated hands-only version (Stage 1), and Fig. 1b shows the final stage of development. Feedback throughout was obtained from computer scientists (n=3), commercial developer/artist (n=2) physiotherapists (n=2), occupational therapists (n=6), psychologist (n=1) and a person with stroke (n=1). Initial focus of the feedback was informal and depending on the expertise or experience of the user. It predominantly focused on usability and safety, except for clinical researchers/professionals who provided input more on rehabilitation potential or issues, e.g. exercises beneficial to rehabilitation, or task execution improvements for ease of use. Clinical staff suggested helpful ways to train an impaired user and add guidance for tasks within VR, including how best to include feedback on performance and/or outcome. Occupational therapists who used the system commented that more emphasis on auditory rather than visual feedback would be beneficial to avoid sensory overload. Types of feedback need to be personalised per case as users may have different issues. Three core areas were focus for system creation: support for mirroring through 6 DoF, ideally controllerless with minimal system complexity (few sensors as possible), and the inclusion of a user avatar driven by responsive inverse kinematics to help enhance presence and sense of embodiment within VR. These requirements added challenge for system development. Poor estimation of user parameters can cause visual distortion of the avatar limbs, so we had to develop mathematical models to determine joint hinge and rotation movements. We believed these features important for a stroke survivor population (enhance accessibility and usability) and they could enhance the potential for MT to have an impact on improved upper limb function.

Figure 2. a) Mode C, Traditional Mirroring b) Mode B, Offset Mirroring c) Comparison of Mirror Modes

Stage 1 successfully implemented all mirroring modes (Fig.2) through 6 DoF aided by Vive trackers on the user's shoulders. Shoulder trackers helped locate a sagittal mirror plane in the centre of a user's body and thus facilitate robust mirroring of hands through 6 DoF. Stage 2 introduced avatar arms and inverse kinematics to move the arms realistically. This addition helped enhance user perception of mirroring modes, and realistic scaling of the avatar limbs improved acceptability/usability. As we did not track a user's elbow position (we chose not to use additional sensors), elbow position and orientation needed to be inferred. Though fine-tuning of the inverse kinematic system parameters improved avatar motion quality, we continued to implement full body inverse kinematics in Stage 3 to further enhance user agency. As expected, the user felt more connected to their virtual 3D avatar arms – being now connected to a virtual body that moved when they did. With full body animation, inference of body joints not directly sensed demanded more fine-tuning of the kinematics system. Replacement of hand controllers with Leap Motion hand sensors in Stage 4 had significant positive impact on embodiment and a sense of presence. However, Leap Motion sensors are more prone to losing tracking due to occlusion issues or a hand moving out of the sensor's view cone. We experimented with several approaches to address these issues; on loss of tracking, including animating the user's arm to a front or side location (until tracking was restored) or leaving it stationary in position (the case with some commercial VR systems). Tracking loss caused further challenges with inverse kinematics and smooth animation of the user avatar. Shoulder trackers proved excellent in aiding 6 DoF mirroring but required additional sensors a user had to put on and wear. So, Stage 5 saw an approach that could infer shoulder position, inferred only from HMD and Leap Motion hand tracking data. While able to implement a system that inferred the required joints, it is currently only robust in mirrored mode while facing forward, but this adequate for most applications of upper arm rehabilitation. As our system development progresses, full 6 DoF mirroring capability is preferred being more robust and supportive of a wider range of activities. For further experiments, it is likely we will use trackers or an external camera to recognise shoulders and other body joints.

Table 1. *Evolutionary development stages for VR mirror system using Vive VR headset (HMD).*

Stage	Description	Design Goal	Evaluation
1	- Avatar hands only - Vive trackers for shoulder tracking - Vive controllers hand tracking	Initial proof of concept mirror VR system creation. Evaluating 6 DoF with appropriate gross motor tasks suggested by	*User*: Tasks were fun, Mode A with 'no mirroring' is easiest, Mode B, with 'offset mirroring' was easier than Mode C 'traditional Mirroring' The disembodied 'floating' hands seemed a little strange for some people. *System*: Combination of custom fitting of trackers to shoulders, hand held controllers, and HMD tracking enabled good location of mirror plane, and effective mirroring of user hands.
2	- Full avatar arms - Initial inverse kinematics - Vive trackers for shoulder tracking - Vive controllers	Increase immersion and presence potential through the addition of avatar arms - by adding a reference point for body motion using trackers on shoulders.	*User*: The additional visualisation of arms provided useful feedback of their hand position, especially in mirror mode. *System*: Small perceived discrepancies between avatar model size to user's actual limb size which can be noticeable in VR affect presence.
3	- Full body inverse Kinematics - Vive trackers - Vive controllers	Further enhance immersion and presence potential by adding full body inverse kinematics. Focus on tailoring.	*User*: Fully body avatar is much more immersive than upper limb only. It appeared to make tasks easier than previous stages, providing a better sense of embodiment in the avatar. *System*: Minor mismatches or distortions are quickly picked up by the user, can make control more difficult and potentially reduce presence.

4	- Full body inverse Kinematics - Vive trackers for shoulder tracking - Leap Motion hand tracking	Implementation of the Leap Motion Controller for Hand andfinger motions / recognition	*User*: The use of hand appeared to enhance immersion - users spent time just playing and looking at their virtual hands. *System*: Tracking of user hands is occasionally lost due to being outside Leap Motion's field of view or in rare cases, occlusion. This has more impact with full body inverse kinematics and mirroring – the system needs to handle loss of tracking elegantly to reduce possibility of break in presence.
5	- Full body inverse Kinematics - Inferred shoulder position - Leap Motion	Remove Trackers for easier set up helping impaired users to be able to set up more easily on	*User*: Much easier system set up for the user and was more intuitive to use. *System*: This was a much more challenging system design, as inferring shoulder position is difficult. Full 6 DoF requires some additional R&D and it may be more effective to simply track shoulders via a camera (though this complicates setup for user).

4. CONCLUSIONS

Evidence suggests MT benefits stroke survivors with one severely disabled upper limb, while their other is much less impaired. Via the reflection 'trick' to the brain it is possible to recover motor function through neuroplasticity and forming new neural circuits to control arm movement. In this paper we presented a VR mirror system and described its design evolution and development through a user-centred design process. Our system development goal is to have a controllerless system and different mirroring modes, in which the user need only wear the headset to access their rehabilitation. We also intend the system to function through 6 degrees of freedom – meaning the user can move fully around a VE and access MT. We have not found any current system offering this mode of operation. We believe our system design increases user agency through providing a heightened sense of presence, immersion and embodiment in an inverse kinematic driven avatar, thus having the potential to enhance a stroke survivor's recovery through the use of MT. However, this hypothesis requires further investigation through experiments, first with healthy users, and then with stroke survivors.

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Cognitive impact evaluation of multimodal interfaces for people with visual disabilities

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ABSTRACT

Visual disability has a major impact on people's quality of life. Even though many technologies exist to assist people who are blind, most of these applications do not necessarily assure the impact of the intended use. This paper presents work in progress on the design of guidelines for evaluating the impact of using multimodal interfaces on cognitive development and enhancement in people who are blind. We report the results of a systematic literature review with the purpose of understanding how the cognitive impact is evaluated on the use of multimodal interfaces for people who are blind. In this paper, we also present an overview of the papers related to cognitive impact evaluation found and how these papers are distributed in the research groups around the world.

1. INTRODUCTION

Visual disability has a major impact on the quality of life of people with visual disabilities including their ability to study, work and to develop personal relationships (Bamac et al. 2004). In this respect, technologies, such as serious games (Sánchez et al. 2015) and assistive technology (Weber 1998; Dalton 2015), have been designed to help people who are blind to supports daily life activities. These technologies work as aids to facilitate independence, autonomy and safety. Accordingly, such technologies can improve the quality of life of these people and stimulate and develop several skills such as cognitive skills (Darin et al. 2015).

Even though there is technology specially focused on people with visual disabilities, we observe that these people are still using logical and organizational level applications that are similar to common applications for the general population beyond people who are blind. For example, Battleship was one of the earliest games to be produced as a computer game with its release in 1979 (Hinebaugh 2009). AudioBattleShip, a version for both children who are blind and sighted allowing them play together, came many years after (Sánchez et al. 2004). In general, people who are blind have particular human-computer interaction needs and the user interface should be suitable for them.

Considering these multimodal interactions (Dumas et al. 2009) with interfaces for people who are blind, it is necessary to verify whether the technologies thought for them are effective and how they impact users in cognitive dimensions. In relation to the quality of applications, the No Child Left Behind (NCLB) Act defined that research in inclusive education must (a) utilize the scientific method, (b) be replicated in more than one set by more than one investigator, and (c) result in findings that converge to a clear conclusion (Alicyn Ferrell 2006). Thus, some studies in this area use Evidence-Based Practice (Sánchez et al. 2004; Sánchez & Galáz 2007), which meets prescribed criteria related to the research design, quality, quantity, and effect size of supporting research (Weber 1998; Dalton 2015). In consequence, the method provides the measurement of the impact of using technology.

Effective impact evaluation which has been used as evidence-based in other domains for users with and without disabilities, should, therefore, be able to assess precisely the mechanisms by which people with visual disabilities are developing or enhancing cognitive skills (Darin et al. 2015). According to these researchers, there is a gap of studies proposing instruments and methods for evaluating the cognitive impact in the context of using multimodal video games for cognitive enhancement of people who are blind. In general, literature-related works gathered in our search do not follow guidelines to support cognitive impact evaluation of multimodal interfaces for people who are blind.

In searching of how the cognitive impact is evaluated on the use of multimodal interfaces for people who are blind, we use a systematic literature review. State-of-the-art aims to review the existing evidence concerning the impact evaluation of multimodal interfaces and also seeks to summarize the empirical evidence concerning the strengths and limitations of a specific evaluation method (Kitchenham & Charters 2007). We also expect to create a bibliographic review based on the steps proposed in the systematic review approach.

The main research question for our first systematic review was "How is the cognitive impact evaluated on the use of multimodal interfaces for people who are blind?" For a better understanding, as a second goal question, we aim to learn "what are the challenges regarding impact evaluation in this scenario?". In this paper, we also present an overview of the papers related to cognitive impact evaluation found and how these papers are distributed in the research groups around the world.

2. STATE-OF-THE-ART

The state-of-the-art methodology consists in a Systematic Review process (Kitchenham & Charters 2007) that aims to review the existing evidence concerning the impact evaluation on the use of multimodal interfaces and also seeks to summarize the empirical evidence concerning the strengths and limitations of a specific evaluation method (Kitchenham & Charters 2007). In contrast to an ad hoc literature review, the systematic review is a methodologically rigorous analysis and study of research results. We intend to identify study opportunities related to the impact of using multimodal interfaces for cognitive development and enhancement in people who are blind.

The initial process of this research method, which consists in a systematic review process to analyse how studies evaluate the cognitive impact in the context of multimodal interfaces for people who are blind, was published in the paper "Cognitive Impact Evaluation of Multimodal Interfaces for Blind People: A Systematic Review" (Mesquita et al. 2018). Following this study and publication, we added a snowballing process (Wohlin 2014), based on compounding the systematic view and understand the coverage of the cognitive impact on this area. The entire process was stored in an excel worksheet available online[1].

For the purpose of this research, we define a research criterion for accepting the research studies: The papers must present technology for people who are blind considering the implementation of user evaluation; the technology includes mobile application, computer software, IoT systems, a virtual environment or a video game with multimodal interfaces; the user evaluation should be a cognitive impact evaluation. For the technologies, we consider more types beyond multimodal video games and virtual environments. By doing so, we aim to obtain more data and not excluding methods that could also be related to multimodal video games and virtual environments. We divided the data acquired from all papers in the four categories: (i) General, (ii) Classification, (iii) Research, and (iii) Empirical. The data that came from the empirical category gave a substantial part for the development of the guidelines.

4. EARLY RESULTS

The systematic review had three filters in the first part and other three more filters in the snowballing process. Figure 1 shows the numbers of papers selected in each filter in the first part and second part, the snowballing. After all filters, the forward and the backward snowballing add 59 papers to the papers already selected. The main reason for withdrawing a paper in the last filter was "the paper's evaluation is out the search", which mainly consider the evaluation focused on the system performance and not on the user cognitive impact assessment.

Among the papers selected, 29 papers are journal paper, the same quantity is conference papers, and only one paper is a book chapter. The main conferences where the papers selected are published (with more than three papers retrieved) are ACM SIGACCES (https://assets18.sigaccess.org/), ICDVRAT (https://www.icdvrat.org/),and UAHCI (http://2018.hci.international/uahci). The leading journal with more than three papers retrieved is the International Journal on Disability and Human Development (https://www.ncbi.nlm.nih.gov/labs/journals/int-j-disabil-hum-dev/). Among these papers, the number of papers per year shows that the research that applies the impact evaluation is well distributed between 2000 and 2017 (top bound year) with a mean of 4 papers and a peak in 2011 (7 papers).

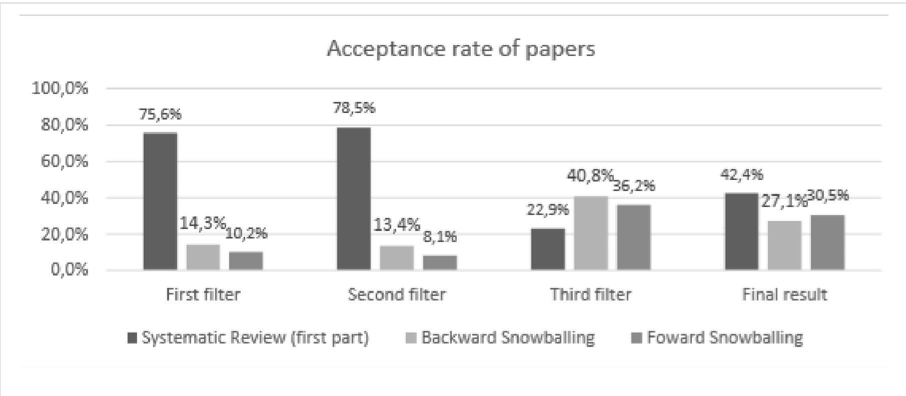

Figure 1. *Acceptance of papers in each filter and final result*

[1]https://www.dropbox.com/s/heywwzbtsvcgrd7/Systematic%20Review%20-%20ICDVRAT.xlsm?dl=0

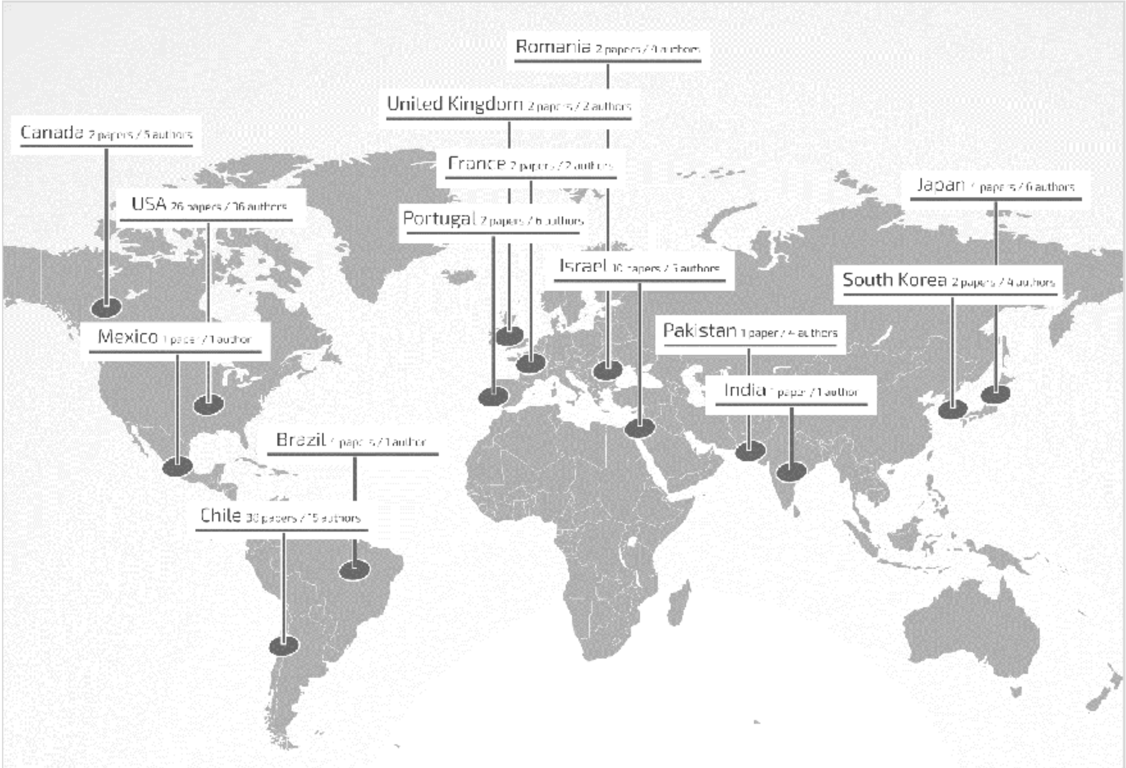

Figure 2. *Global overview of cognitive impact evaluation*

Figure 2 shows the global overview of the papers retrieved in the systematic review. We explore the locations by using the MAXQDA[2] software to correlate the groups around the world. As we can see in the figure, the leading research groups in this context are in Chile, USA, and Israel. Specifically, they are from the Department of Computer Science at University of Chile (36 papers), Laboratory for Visual Neuroplasticity at Harvard Medical School (8 papers), School of Education at Tel Aviv University, Israel (7 papers) and PUCRS in Brazil (4 papers).

4. CONCLUSIONS

With this ongoing work we expected to create a bibliographic review on the cognitive impact evaluation of using multimodal interfaces by people who are blind based on the steps of the systematic review approach. Although there is a need for verifying the quality of technologies (Alicyn Ferrell 2006) and to explore how they impact users in cognition (Darin et al. 2015), cognitive impact assessments are still restricted to a few groups. Effective impact evaluation could be used as evidence-based to assess precisely the mechanisms by which people with visual disabilities are developing or enhancing cognitive skills. In this paper, which adds information to a previous publication related to this work (Mesquita et al. 2018), we present an overview of the papers encountered highlighting the main authors and research groups. Next step on this research is the use of the Grounded Theory method applied on data from the systematic review with the purpose to improve the data analysis and create a set of guidelines that appropriately guide experiments for evaluation of the cognitive impact of using multimodal interfaces by people who are blind. These guidelines will provide a framework for a formal and methodological way to implement this evaluation process.

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[2] https://www.maxqda.com

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Is it necessary to show virtual limbs in action observation neurorehabilitation systems?

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ABSTRACT

Action observation neurorehabilitation systems are usually based on the observation of a virtual limb performing different kinds of actions. In this way, the activity in the frontoparietal Mirror Neuron System is enhanced, which can be helpful to rehabilitate stroke patients. However, the presence of limbs in such systems might not be necessary to produce mirror activity: for example, frontoparietal mirror activity can be produced just by the observation of virtual tool movements. The objective of this work was to explore to what point the presence of a virtual limb impacts the Mirror Neuron System activity in neurorehabilitation systems. This was done by using an action observation neurorehabilitation task during an fMRI experiment with healthy volunteers and comparing two action observation conditions that: 1-included or 2-did not include a virtual limb. It was found that activity in the Mirror Neuron System was similar during both conditions. These results open up the possibility of using new tasks that do not include virtual limbs in action observation neurorehabilitation environments, which can give more freedom to develop such systems.

1. INTRODUCTION

Mirror neurons, originally discovered by using intracranial electrodes in the premotor and the parietal cortex of monkeys, discharge not only when individuals perform a particular action (e.g., reaching for a piece of food) but also when they observe others performing the same or a similar action (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996, 2002). This discovery was an important milestone in neuroscience, because it showed that action perception and action execution were intrinsically linked from the neuronal level. Later research in humans with non-invasive neuroimaging and neurophysiological techniques showed evidence of the existence of a frontoparietal cortical network with the same property, which has been called the Mirror Neuron System (MNS) (Cattaneo & Rizzolatti, 2009).

The essential property of mirror neurons (i.e., their activation by both executed and perceived actions) has a clinical application in the field of neurorehabilitation. This approach is based on the visual presentation of actions (e.g., using a mirror or virtual reality) to increase the activity in the MNS, as this activity can facilitate the reorganization of the brain motor regions affected by stroke (Bhasin, Padma Srivastava, Kumaran, Bhatia, & Mohanty, 2012; Buccino, Solodkin, & Small, 2006; Garrison, Winstein, & Aziz-Zadeh, 2010; Sale & Franceschini, 2012). This kind of approach can be helpful to rehabilitate patients who cannot perform some active movements as a result of a cerebrovascular accident.

Action observation rehabilitation systems are usually based on the observation of a virtual limb performing different kinds of actions; for example patients can observe approaching virtual objects that are intercepted by virtual arms (Cameirão, Bermúdez i Badia, Duarte Oller, & Verschure, 2010; Cameirão, Bermúdez i Badia, Zimmerli, Duarte Oller, & Verschure, 2007), thereby activating their MNS (Prochnow et al., 2013). However, representing the limbs in such systems may not be necessary to produce mirror activity: in a previous experiment we have shown that extensive MNS activity can be produced just by the observation of a virtual paddle movement (Modroño, Navarrete, Rodríguez-Hernández, & González-Mora, 2013).

The objective of the present research is to explore to what point the presence of a virtual limb is necessary to produce mirror activity in a neurorehabilitation system based on action observation. This was done by using an action observation neurorehabilitation task and comparing conditions that present or do not present a virtual limb to healthy volunteers in an fMRI experiment. Based on previous research (Modroño et al., 2013; Prochnow et al., 2013), we expect to find mirror activity in both conditions (note that these conditions were not directly compared in those experiments). Interestingly, if the activations are similar in both conditions, this would have important implications for the development of virtual environments: this would open up the possibility of using new tasks that do not include virtual limbs, giving more freedom to develop virtual environments.

2. METHODS

2.1 Participants

14 (4 female, 10 male) right-handed neurologically healthy subjects (mean age=22.8, SD=1.9). They had normal or corrected-to-normal vision. The study was approved by the local Ethics Committee (University of La Laguna) and was conducted in accordance with the Declaration of Helsinki.

2.2 Neurorehabilitation task

Participants were involved in an action observation neurorehabilitation task as shown in Figure 1. The task is a simplified version of the Reh@Task (Faria et al., 2016), a VR system that presents a cancellation task with one image as target among 4 distractors. The task is solved by moving a virtual cursor and placing it over the target element for 5 seconds. The system is programmed to solve the tasks automatically (by using inverse kinematics, skeletal constraints are considered and the movement is physically correct and plausible), presenting to the user either 1) a virtual hand with a red dot under the tip of the middle finger or 2) just a red dot performing the selection process. After completion, the task restarts the process with a new randomly selected target and distractor elements.

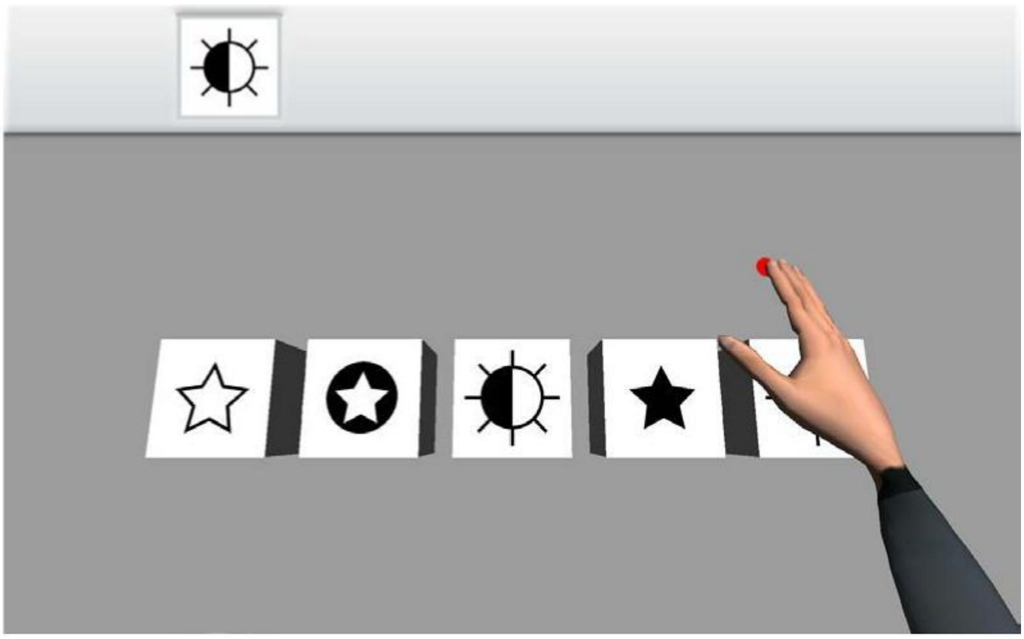

Figure 1. *The action observation task. Participants observed movements of a virtual limb with a red dot under the tip of the middle finger (hand condition, shown here), or equivalent movements of the red dot alone (dot condition). In both cases, the red dot moves to reach the figure indicated in the left top corner of the screen.*

2.3 Data acquisition

The fMRI run consisted of three conditions: *dot*, *hand* and *fixation*. The *dot* condition consisted of 6 blocks (58s) of 11 trials each, where the participant observed the movements of the dot. The *hand* condition was similar, but in this case a virtual limb appeared above the dot (Fig 1). The *dot* and *hand* blocks were presented in random order and were preceded by a fixation task where the player stared at a grey cross in the middle of a black screen (baseline). The same random sequence of blocks was kept for all participants. The participants were instructed to focus on the movements of the dot and the hand during the corresponding conditions. Before the observation task, participants played a hand-controlled version of the same task for 6 minutes to link those actions to their motor repertory (by using a joystick). Visual stimuli were given via MRI compatible eyeglasses (Visuastim, Resonance Technology, Northridge, CA).

Axially oriented functional images were obtained by a 3T Signa HD MR scanner (GE Healthcare, Milwaukee, WI) using an echo-planar-imaging gradient-echo sequence and an 8 channel head coil (TR = 2000 msec, TE = 21.6 msec, FA = 75º, matrix size = 64 x 64 pixels, 36 slices, 4 x 4 mm in plane resolution, spacing = 4 mm, ST = 3.3 mm, interleaved acquisition). The slices were aligned to the anterior commissure - posterior commissure line and covered the whole brain. High resolution sagittally oriented anatomical images were also collected for anatomical reference. A 3D fast spoiled-gradient-recalled pulse sequence was obtained (TR = 8.84 msec, TE = 1.75 msec, FA = 10º, matrix size= 256 x 256 pixels, 1 x 1 mm in plane resolution, spacing = 1 mm, ST = 1 mm).

2.4 Data analysis

Data were preprocessed and analyzed using SPM12 software (www.fil.ion.ucl.ac.uk/spm/). The images were spatially realigned, unwarped, normalized and smoothed using standard SPM12 procedures. The three conditions were modelled in the design matrix for each participant. Activation maps for the contrast *dot* > *fix*, *hand* > *fix*, *hand* > *dot* and *dot* > *hand* were generated for each subject by applying t statistics. These first level contrast images were used in a random effects group analysis. Statistical maps were set at a voxel-level threshold of $p<0.05$, false discovery rate [FDR] corrected for multiple comparisons, and a minimum cluster size of 25 voxels.

3. RESULTS

Figure 2 shows the brain regions that were activated by the action observation neurorehabilitation task. The task was associated with an increase of activity in bilateral frontoparietal regions of the MNS (parietal lobe, premotor cortex plus, caudal part of the inferior frontal gyrus) (Cattaneo & Rizzolatti, 2009) not only when the virtual hand was moving but also when the virtual hand was absent and only the dot was moving. Other regions outside the MNS, such as the occipital lobe and the cerebellum were also bilaterally activated in both conditions. Interestingly, no significant differences in brain activity were found between the *hand* and the *dot* conditions (*hand* > *dot* and *dot* > *hand* contrasts).

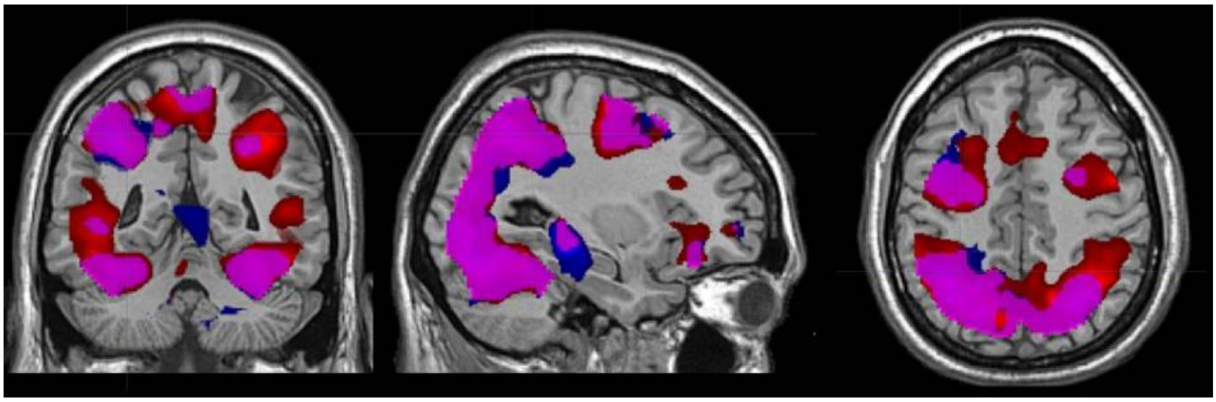

Figure 2. *The action observation neurorehabilitation task was associated with an increase of activity in the Mirror Neuron System when the virtual hand was moving but also when the virtual hand was absent and just the dot was moving. Blue voxels were activated only in hand condition (hand > fix contrast); red voxels were activated only in dot condition (dot > fix contrast); violet voxels depict regions activated in both conditions (both contrasts). The contrasts hand > dot* and *dot > hand did not show significant results. Group analysis, N=14, threshold: p<0.05 at the voxel level, False Discovery Rate corrected for multiple comparisons; minimum cluster size=25 voxels.*

4. CONCLUSIONS

As expected, the two main conditions (*hand/dot*) of the action observation task activated the MNS of the participants. Regarding the *hand* condition, the participants were observing the movements of a virtual arm, thus finding activity in the MNS is consistent with previous research on action observation rehabilitation systems that have presented virtual limbs in their tasks (Prochnow et al., 2013). Concerning the *dot* condition, we also found activity in the MNS although the participants were just observing the movements of a dot. This is also consistent with previous research showing that MNS activity can be produced just by the observation of virtual tool movements (Modroño et al., 2013).

More interestingly, we have directly compared two conditions that only differed in the presence or absence of a virtual limb, and we did not find significant differences in associated MNS activity. In this way, the activity we found during the *hand* condition does not appear to be so directly related with the observation of the limb but more with the observation of actions that had been previously linked to the observer's motor repertory during the practice period (Modroño et al., 2013).

The results presented here may be of interest for researchers and developers of neurorehabilitation systems based on action observation, and could be used to make the systems more attractive for the patients (for example, combining different kinds of tasks including or not including virtual limbs), which therefore may help the patient to adhere to the therapy.

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Literature review and design concept to read bio-data from wearable assistive device and synchronising it with music to support people living with dementia

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ABSTRACT

The positive changes in human behaviour caused by relaxing music demonstrate the psychological effect of music on the human body. Meta-analytical studies have shown that relaxing music affects blood pressure and heart rate in coronary heart patients and cancer patients. In line with the above studies, this research will investigate the influence of music on people with early symptoms of dementia.

The proposed study aims to investigate if there is a significant effect on heart rate and heart rate variability when listening to relaxing music, particularly in those people who are prone to mood changes, anxiety and ailments exhibited by early symptoms of dementia. It aims to determine if the presence or absence of music affect anxiety levels.

To proceed, this research will conduct a systematic literature review to confirm if the presence or absence of music affect anxiety levels in people living with dementia. This will support to facilitate the design and the development of a usable interface technology that will allow monitoring of bio-data and controlling them with the integration of music.

This work is part of our current inter-disciplinary research project which is to provide a suitable model and software prototype to accurately analyse data from wearable devices and synchronise it with music in order to support people living with dementia.

1. INTRODUCTION

The use of sensory devices to monitor the physiological data of people living with early symptoms of dementia and to be able to analyse the sensory output would assist to identify deviations from normal patterns and can indicate symptoms of restlessness, anxiety and changes in mood.

1.1 Dementia symptoms

Dementia is a clinical condition which affects the intellectual functions of the brain associated with remembering, thinking and making decisions.

Depression, anxiety, apathy and agitation are common characteristics of behavioural and psychological symptoms exhibited by people diagnosed with dementia. Chemical changes in the brain, caused by dementia, can lead to depression or anxiety.

In general, symptoms of anxiety include fast or irregular heartbeats (palpitations), shortness of breath, excessive sweating, drop or rise in temperature, headaches, trembling and dizziness. [2].

It should be noted that, some of the symptoms mentioned above are directly linked with both high and low cortisol levels. Blood pressure and body temperature are two things that can provide some insights to help prompt a medical personnel to order a series of cortisol tests.

Behavioural and Psychological Symptoms of Dementia, labeled as (BPSD), affect more than 90% of people who suffer from dementia [3]. BPSD encompasses symptoms of agitation, delusions, euphoria, hallucinations, apathy, depression, aberrant motor behaviour, insomnia, irritability, changes in eating patterns, memory difficulties, confusion, depression, and body temperature regulation problems such as chills, hot flushes, and night sweats.

1.2 Empatica E4 wearable band

The Empatica is a wearable wireless multisensory device for real-time computerised bio-feedback and data acquisition. It has four embedded sensors; photoplethysmograph (PPG), electrodermal activity (EDA), 3-axis accelerometer and temperature sensor. The E4 operates in streaming mode for real-time data processing using Bluetooth technology and in recording mode using its internal flash memory. [9]

1.2.1 Photoplethysmography sensor (PPG)
This measures blood volume pulse (BVP), from which heart rate, heart rate variability, and other cardiovascular features can be derived. With each cardiac cycle, the heart pumps blood; the pressure wave produced by the heart beat is correlated to a change in the concentration of oxy-hemoglobin. Oxy-hemoglobin absorbs light at certain wavelengths; therefore, the more oxy-hemoglobin is present in the blood, the more light is absorbed. The PPG sensor illuminates the skin and measures the light reflected. [9]

1.2.2 Electrodermal activity sensor (EDA)
This measures the constantly fluctuating changes in certain electrical properties of the skin; skin conductance value (sweat gland activity). High sweat gland activity indicates sympathetic nervous system arousal that exhibit features related to stress, engagement, and excitement. [9].

1.2.3 Temperature
Skin temperature is recorded with an optical infrared thermometer. Stress and anxiety, can increase the body's metabolism and in turn, increase body heat [9]. High cortisol levels often cause elevated body temperatures.

1.2.4 3-Axis Accelerometer
3-axis accelerometer allows to capture motion-based activity. Significant changes in readings will indicate possible signs of agitation and anxiety symptoms that are exhibited by people living with dementia. [9]

2. RESEARCH APPROACH

This main focus of this paper is to derive a holistic view of existing literatures related to the efficacy of music to support people living with dementia. It will aim to systematically review existing literature in order to answer the following research question to support the research topic.

Does the presence or absence of music affect anxiety levels in people living with dementia?

2.1 Search resources
Search was carried out for relevant articles published in English within journals and conference papers dating from 2015 onwards to ensure that findings were most up to date. Search resources used were CINAHL, MedLine, PubMed and Web of Science accessible through the University's library subscription.

2.2 Search strings
Search was carried out using a combination of search terms in order to address the research question stated above. The defined search string was ("dementia" AND "music" AND "anxiety"). Some papers appeared in more than one electronic database and thus duplicates were removed.

Table 1. *Papers reviewed*

	CINAHL	MedLine	PubMed	Web of Science
Initial selection	7	25	30	49
Filtered selection	4	7	5	9

3. ANALYSIS OF FINDINGS

For each of the 25 filtered papers reviewed, use of music to support anxiety and related symptoms in dementia were recorded and analysed to give a clearer picture of the therapeutic effect of music in healthcare to support people living with dementia and in turn provide an answer to research question outlined.

From the results obtained in addressing the research question, the following can be deduced:

Table 2. *Summary of Findings*

1	Music based interventions have helped to reduce anxiety levels in people living with dementia. (14 papers)	[1], [3], [5], [8], [10], [11], [14], [17], [18], [20], [21], [22], [23], [25]
2	Music has a positive effect on memory. (15 papers)	[1], [2], [3], [5], [8], [9], [12], [14], [17], [18], [20], [21], [22], [24], [25]
3	Music therapy could be a viable alternative to pharmacological treatments. (10 papers)	[1], [7], [8], [9], [12], [14], [16], [19], [24], [25]

This confirms that music is effective and can be utilised as a non-pharmacological treatment for people living with dementia. It is evident from this research that music has given rise to a rapid growth in non-pharmacological treatment in healthcare particularly when dealing with cognitive and behavioural symptoms depicted by people living with dementia.

4. PROPOSED SYSTEM TO SYNCHRONISE MUSIC WITH BIO-DATA

The research project will facilitate processing of bio-data from wearable devices in real-time and allow scheduling of chosen music as a therapeutic treatment to reduce levels of anxiety, apathy and agitation.

- Information from patients using wearable device will be read in real-time.
- Data streams will be processed in real-time to detect variations in the patient's bio-data from the wearable device.
- Variations in bio-data readings will automatically trigger scheduling of music
- Dementia assessment tools will be implemented to evaluate the outcome measure of music therapy.

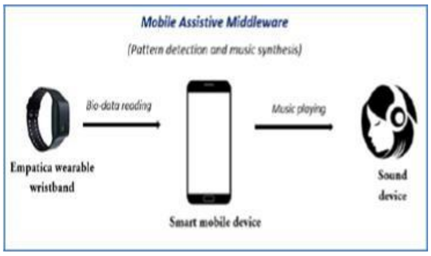

Figure 1. *Mobile Assistive Middleware*

5. CONCLUSION AND FUTURE WORK

Motivation for the research is that wearable devices together with music can play a useful role in building dementia support systems by intelligently providing soothing and therapeutic effect on patient behaviour to dementia symptoms defined by clinical guidelines in order to assist medical aid and support.

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Validity of the internet-based Bill-Paying task for assessing executive functions in adults with traumatic brain injury

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ABSTRACT

Background: Executive Function (EF) deficits following Traumatic Brain Injury (TBI) have a significant impact on the ability to function independently in everyday life. Therefore, during rehabilitation, there is great importance in identifying these deficits by using performance-based assessment tools that highlight the difficulties while performing an everyday activity, such as online bill payment.

Objective: To examine the validity of the Internet-based Bill-Paying task from the Executive Function Performance Test for assessing EF deficits in adults with TBI.

Method: This cross-sectional study included 42 adults with TBI, who were undergoing rehabilitation, and 47 healthy adults. All participants performed the Internet-based Bill-Paying task and a comparison between groups was made to establish construct validity. In addition, participants with TBI completed the WebNeuro neurocognitive computerized assessment battery and the Functional Independence Measure (FIM) was used to assess their independence in basic activities of daily living.

Results: Significant differences were found between groups in the time to complete ($t=-4.8$, $p<.01$) and scoring ($t=-5.6$, $p<.01$) of the Internet-based Bill-Paying Task. In the TBI group, significant correlations were found between Internet-based Bill-Paying task and the Stroop and Maze subtests ($r=0.33$, $p<.05$; $r=0.51$, $p<.01$, respectively) of the WebNeuro, verifying that this task entails EFs. A significant correlation was found between their performance of the Internet-based Bill-Paying Task and the FIM scores ($r=-0.41$, $p<.01$).

Conclusions: The construct validity and initial criterion validity of the Internet-based Bill-Paying task for assessing EF deficits in adults with TBI were established. This internet-based assessment can be used with adults with TBI to identify EF deficits and assist with treatment planning.

1. INTRODUCTION

Traumatic Brain Injury (TBI) is a prevalent public health problem throughout the world. In Europe, the estimated prevalence was found to be around 7,775,000 and the yearly average incidence rate was found to be 326 cases per 100,000 (Peeters el al., 2015). One of the main consequences of TBI are executive function (EF) deficits (Centers for Disease Control and Prevention, 2015). EFs are defined as integrative cognitive processes that determine goal-directed and purposeful behaviour (Cicerone et al., 2000). EF deficits can affect interpersonal relationships and contribute to poor community, social and occupational integration, which impairs the person's ability to work, perform household tasks, drive or participate in other activities of daily living (Faul, Xu, Wald, & Coronado, 2010; Lezak, 2004).

Accurate assessment of EF is essential to plan a comprehensive rehabilitation program (Lewis & Leathem, 2011). Traditionally, neuropsychological assessments have been considered the gold standard to assess EF deficits (Hahn et al., 2014). However, the relationship between performance in these assessments and performance in everyday tasks is unclear (Connor & Maeir, 2011). Furthermore, neuropsychological assessments have been criticized as having limited ecological validity, i.e.limited ability to generalize to real-world functioning (Burgess et al., 2006). It is therefore critical for practitioners to use performance-based assessments relevant to performance in the real world (Connor & Maeir, 2011; Hahn et al., 2014).

The Executive Function Performance Test (EFPT; Baum et al., 2008) is a well-known, valid and reliable performance-based assessment to assess components of EF while performing everyday tasks (Baum et al., 2008; Katz, Tadmor, Gelzen & Hartman-Maeir, 2007). For each task, the following EF components are assessed: (1) initiation, (2) organization, (3) sequencing, (4) safety and judgment, and (5) completion. Recently, the bill payment task from the EFPT was modified for internet use, where the cheques for the bill-paying task were replaced by a mock credit card and balancing the account was replaced by the line of credit (Figure 1). The Internet-based Bill-

Paying task can be freely downloaded from the following link: https://www.tau.ac.il/~portnoys/Internet-based_Bill_Paying_Task.html.

The Internet-based Bill-Paying task provides quantitative performance data (e.g., time to complete the task, time spent on each web page, and number of mouse clicks) in addition to the traditional scoring of the assessment based on cueing provided by the occupational therapist, who observes the client's performance. Alternative-form reliability, construct and criterion validity for the Internet-based Bill-Paying task were verified in adults with stroke, adults with attention deficit hyperactivity disorder and healthy adults (Rand, Ben-Chaim, Malka & Portnoy, 2018).

The aims of this study were: 1) To compare the performance of adults with TBI to healthy adults (establish construct validity), 2) to correlate performance of Internet-based Bill-Paying task with neurocognitive assessments and an everyday functional measure (establish criterion validity).

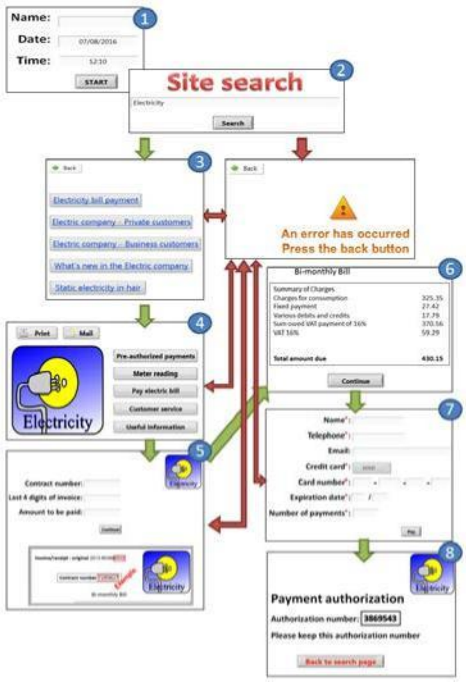

Figure 1. *Screen shot examples from the Internet-based Bill-Paying task.*

2. METHODS

A cross-sectional study including two groups of participants.

Participants. Participants with mild to severe TBI (*n*=42) were recruited, using convenience sampling, from a large rehabilitation center. Inclusion criteria were diagnosis of TBI, age >18 years, ability to understand the instructions of the assessment tools as was determined by their occupational therapist, a motor ability to use the computer, basic computer skills as was determined by a questionnaire, intact or corrected vision, preserved basic cognitive abilities as was determined by three subtests of the Loewenstein Occupational Therapy Cognitive Assessment (LOTCA): orientation (score: 6/8 or above), visual perception (score: 3/4 or above) and spatial perception (score: 3/4 or above). Healthy participants (*n*=47) were recruited by advertisements posted at the university and in a rehabilitation center. Inclusion criteria were at least 12 years of education, independent living in the community, and previous use of computers. Exclusion criteria for all participants were epilepsy, psychiatric or neurologic conditions. The study was approved by Loewenstein Rehabilitation Center's Helsinki committee, as well as the university's ethics committee. All participants provided written informed consent.

Tools and Procedure. The Internet-based Bill-Paying task: scoring of each component is based on the level of cueing that is provided for the client to complete the task, ranging from 0 (no cue required) to 5 (do for the participant), higher scores indicate more EF deficits. The highest level of cueing necessary to support task performance is recorded, scores range for each task from 0 to 25 points (Baum et al., 2008). In addition, the following computerized data while performing this task were registered: time (secs) on each web page, number of mouse clicks, and mouse travel distance.

The adults with TBI were also administered three subtests from the Webneuro computerized assessment battery (Brain Resource Ltd., 2010) which were used to assess EFs: 1. Maze– the time it takes to identify and learn a hidden path through trial and error. The maze assesses the capacity to plan and organize behaviour to meet a goal, 2. Stroop - capacity to stop automatic reactions and thoughts as needed, 3. Go-no-Go– the response time to a correct stimulus.

It assesses the capacity to suppress an inappropriate response (Silverstein et al., 2007). Scores for participants who did not complete the tasks within the time constraints were not recorded.

The Functional Independence Measure (FIM) score, ranging from 18-126 points, was extracted from the participant's medical record adjacent to the time of research. The FIM assesses the level of independence of the person, from 1 (dependent) to 7 (independent) for 18 activities of daily living, such as dressing, bathing and walking (Keith, Granger, Hamilton, & Sherwin, 1987).

Data Analysis. Data were analyzed using IBM SPSS Statistics (Version 23; IBM Corp., Armonk, NY). Since the data were not normally distributed, descriptive statistics were presented as median and Inter Quartile Range (IQR) and non-parametric statistics were used. Descriptive statistics were used to describe the demographic and injury related information of the study population, the Internet-based task scores, the WebNeuro subtests and the FIM. Mann-Whitney U test was conducted to assess the differences between groups. Spearman correlations were used to assess associations between the Internet-based task to the WebNeuro subtests and the FIM for the participants with TBI. The statistical level was set at $p < .05$.

3. RESULTS

This study included 42 adults with TBI (34 men, 8 women), median age of 38.5 years (IQR 23.0-55.5) with 12 median years of education. They were a median of 72.5 days (IQR 44.7-116.5) since their head injury and still undergoing rehabilitation. They were mostly independent in basic activities of daily living with a median FIM score of 105/126 points (IQR 92.7-110.7). According to the screening test, their basic cognitive abilities were intact. All the participants with TBI completed the internet-based Bill-Paying task. This study also included a group of 47 healthy adults (15 men, 32 women), median age was 27 years (IQR 25-60) and median years of education were 14 (IQR 13-15).

Significant differences in the performance and completion time of the internet-based Bill-Paying task (Table 1) were found between the TBI group and the healthy group. In addition, significant differences were found between groups in the computerized measures.

Thirty-eight participants with TBI completed the Stroop and the Maze subtest in the time constraint and their scores were registered; Stroop- median 0 mistakes (IQR 0-1.2), Maze- median 313.7 sec (IQR 229.8-445.9). Significant weak to moderate correlations were found between the internet-based Bill-Paying task (total score) and the Stroop ($r=0.34$, $p<.05$) and Maze subtests ($r=0.42$, $p<.01$). Forty-two participants completed the Go-no-Go subtest- median 0.36 sec (IQR 0.32-0.41), however, no significant correlations were found with the internet-based Bill-Paying task ($r=0.2$, $p=0.064$).

Overall, the participants were independent in basic activities of daily living, as reflected by the FIM median score of 105 out of 126 points (IQR 92.7-110.7). The FIM score was found to be significantly negatively correlated with the Internet-based Bill-Paying task ($r=-0.41$, $p<.01$), so that participants with higher FIM scores, needed less cueing for the Internet-based Bill-Paying task (and vice versa).

Table 1. *Median, interquartile range (IQR) and Differences between the Traumatic Brain Injury (TBI) group and the healthy group for the Internet-based Bill-Paying task. (*n=36)*

	TBI (N=42) Median (IQR), Min-Max	**Healthy (N=47) Median (IQR), Min-Max**	**z, p**
Total score (0-25)	7.0 (3.7-10.0), 0.0-20.0	1.0(0.0-2.0), 0.0-12.0	-5.6, <.001
Complete time (mins)*	23.3 (17.7-29.9), 10.9-64.0	10.0 (8.4-15.6), 3.6-50.3	-5.8, <.001
Time in electricity payment page (mins)*	3.0 (1.9-4.9), 1.0-10.7	1.2 (0.7-1.9), .0.0-6.3	-4.9, <.001
Time in gas payment page (minutes)*	1.8 (1.4-2.7), 0.7-13.4	1.2 (0.8-1.9), 0.3-7.9	-2.7, .006
Total mouse travel (pixels)*	20449 (15667-34082), 8324-76289	15326 (10132-15326), 6088-224727	-2.7, .005

4. DISCUSSION

EF deficits following TBI lead to reduced independence, restricted participation and decreased quality of life (Siman-Tov et al., 2016; Bottari et al., 2009), therefore accurate assessment is important. The Internet-based Bill-Paying task from the EFPT simulates online payment of bills and was used in this study with adults with TBI. The findings from the study provide construct, criterion and predictive validity of the Internet-based Bill-Paying task to assess EF deficits in adults with TBI.

Limitations of this study include missing scores in the WebNeuro subtests for participants who did not meet the time demands of the task. In addition, computerized data were not recorded for some of the participants in the TBI group. Finally, only patients with intact basic cognitive ability were included in this study, therefore, these findings might not generalize to patients with TBI with impaired basic cognitive abilities.

5. CONCLUSION

The internet-based Bill-Paying task is a feasible and challenging task to detect EF deficits in adults with TBI with intact cognitive abilities. The use of this ecological valid task may contribute to a better understanding of the cognitive profile and daily functioning of adults recovering from a TBI. Furthermore, the bill-paying computer performance data might be valuable in detecting subtle deficits in EF. Further research is needed.

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Towards a framework for implementation of virtual reality technologies in schools for autistic pupils

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ABSTRACT

Virtual reality and associated technologies offer unique potential for learning in special educational contexts. Research studies have demonstrated applications of collaborative VR for encouraging and enabling children with autism to communicate and collaborate with other people. Despite the enthusiasm of students and teachers for these applications, implementation of new technologies in schools is challenging and, often, when the support of the research team is no longer available, the technology remains unused. We reflect upon our experiences in two projects in which collaborative VR applications were developed specifically for use in the autism classroom in the UK. Both projects provide extension to a previous methodological framework for VR application in mainstream education (Crosier et al., 2002). We conclude that further development of the framework, including consideration of the wider organisational context, is needed to address issues related to limited uptake in schools.

1. INTRODUCTION

The field of educational technologies and the potential therein has been long discussed and identified as a possible affordance for various groups of learners (Bitner and Bitner, 2002). However, there are many potential challenges to developing technology that can fit and be integrated into classroom settings successfully (Newbutt, 2013; Zhao et al., 2002). This is also the case for designing, developing and integrating technology into classrooms successfully for sustained and long-term deployment. Whilst there has been considerable research focused on technology-based outcomes for use in mainstream schools, we focus specifically on affordances of VR technology and targeted groups such as autistic learners in special needs schools.

Virtual reality (VR) technology has been considered to offer specific advantages for special education including autism: see Parsons and Cobb (2011), Bradley and Newbutt (in press) for an overview. The respective research groups and collaborating partners of the authors have conducted several research projects in which benefits of VR has been demonstrated as a suitable medium in supporting children with autism to practice and improve skills in social interaction (Parsons and Mitchell, 2002), collaboration (Millen et al., 2012), and communication (Newbutt, 2013). Moreover, recent research has shown that teachers quickly identify the affordances/benefits of VR for autism education as follows: practicing social skills at a distance, reduced stress, reduction in face-2-face communication and reduction of real-word consequence (Nussli and Oh, 2016), specifically: "social skills practice and repeated practice opportunities in a stress-reduced environment emerged as the key benefits" (p. 198). However, teachers also identify many barriers to technology and VR uptake within school settings, with key reported challenges classified into three categories: (1) appropriateness; (2) distraction from learning; and (3) technical issues (Nussli and Oh, 2016).

In this short paper, we provide an overview of the approach taken in two example projects, both of which built upon the methodological framework for design, development and evaluation of VR environments for education described by Crosier et al (2002). We then reflect on some of the reasons why the technology was not completely adopted, despite positive outcomes for the user groups (autistic children). We conclude with some messages for future work seeking to better enable classroom integration (of VR tools) for autistic learners.

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2. DEVELOPING A FRAMEWORK FOR IMPLEMENTATION OF INNOVATIVE TECHNOLOGY IN AUTISM SCHOOLS

Previous research exploring the application of VR technology for mainstream education established the importance of involving teachers through all stages of design, development and evaluation of new educational technology using participatory design methods. Crosier et al. (2002) proposed a framework comprising three phases through which the research team worked closely with teachers to develop a VR application for student learning. The framework identified a number of contextual considerations that may affect learning outcome as follows: facilities and equipment, use in the school environment and individual learner characteristics. Subsequent projects applied this framework when developing VR applications for use in special education (Cobb, 2007), each project adding detail to the initial framework. In this paper we summarise two projects that developed applications of collaborative VR for young people with autism. Our reflections are used to provide recommendations for extending the framework further to take a wider perspective, including organisational issues, to facilitate uptake in practice.

2.1 Inclusive participatory design and development of virtual environments for education

The COSPATIAL project (2009-2012) examined utility of the unique affordance of collaborative VEs (CVEs) to support practice in task collaboration and social communication (Parsons et al., 2011). This project extended the framework through consideration of stakeholder contribution to the process. A key feature of the project was the direct involvement of teachers *and* autism professionals *and* pupils with autism in the participatory design process (Parsons and Cobb, 2014). A detailed description of the development process is given in Cobb et al (2014) and shows how these different stakeholder groups contribute in different ways and at different stages of design, development and evaluation (Figure 1, left). The design process involved regular meetings between members of the design team and frequent visits by the researchers to the schools. VR development was conducted in the research lab and iteratively developed in response to feedback from the participatory design team. However, we discovered issues relating to conveyance of conceptual design information of the group leading to differences in expectations and subsequent disappointment with some aspects of the emerging CVE application. This was resolved by improving communication of ideas through duplicating design information in different formats (e.g. low-fi prototype screen shots to illustrate user virtual avatar viewpoints during a given scenario of use, represented as an interaction task flow diagram to convey the complexity and sequence of interaction input decisions needed to support the scenario. This made it easier for system developers to anticipate and articulate the consequences of decision decisions on user interactions and for teachers and learning theorists to recognise how this may enhance, or interfere with, student engagement in the learning task. Two CVE applications were developed with evidence of successful learning outcomes in evaluation studies (Parsons, 2015). However, despite intensive engagement between the project research team and participating schools, use beyond the project was short-lived and not sustained. A force-field analysis of the COSPATIAL project recommended, amongst other things, that development and testing of new technology should be conducted within the context of use; i.e. the special education classroom (Weiss et al., 2014). This approach was taken in our second example project, described below.

2.2 Embedding the research within the classroom

The VIRTAUT project (2009-2012), developed a virtual world (VW) to help facilitate communication and social skills development (Newbutt, 2013). Part of this work was also to consider representation of self (via an avatar) and appropriateness of communication in-world. This project extended the framework by exploring the contextual considerations in more detail. The entire project was conducted within the school context; as a researcher-in-residence, the VW developer worked in a class of eight autistic children aged 15 and 16 (six male) for a period of 12 weeks. This enabled an agile inclusive design process in which the VW was iteratively developed to include visual appearance and interactive features that were responsive to user needs. As in previous projects, a participatory design method was applied in which the researcher and design team worked with teachers, pupils and a school IT manager. In contrast to the COSPATIAL project, embedding the research and development within the classroom meant that contextual and technology-focused factors also played a role in the development of technology deployment. In doing so, we identified several issues that could be resolved quickly and accordingly. For example, issues with the school's Firewall would have meant the project could not be deployed at all; but through early and in situ engagement we were able to overcome this barrier. Moreover, by designing and testing frequently in the classroom, we were able to ensure that user requirements and expectations were maintained and met. This project added to phase two of the Crosier et al. (2002) framework which originally comprised contextual considerations of facilities, equipment, intended school use, and individual characteristics. The VIRTAUT project added several modified/additional considerations to this phase (Figure 1, right). Firstly, by embedding the research and development in the classroom, the researcher gained an appreciation of the room layout and how the space was used everyday; the research activity was not a special occasion in which visitors came to the school to bring new demos for students to test, research and development activities were integrated into the weekly class routine.

Secondly, this meant that the research made use of existing equipment in the school rather than research equipment which may be more expensive and/or of higher specification than the facilities in school. Thirdly, when designing technology to be used in an SEN context, learner needs should be considered in addition to learner characteristics; for example, accessibility issues could lead to different requirements for user interaction with the proposed technology. Fourthly, access to the Internet is a vital requirement for running a VW and it became apparent that bandwidth and port issues were both vital to successful integration of a virtual world; being able to identify and test bandwidth and port information was an important aspect of the development-test process. The requirement for specific ports to be open was essential for access to the VIRTAUT VW, but this could only be authorised by the local educational authority (LEA). Thus, in addition to the contextual considerations of using the technology in the classroom per se, the project added a stage for negotiation with the wider educational system to the framework.

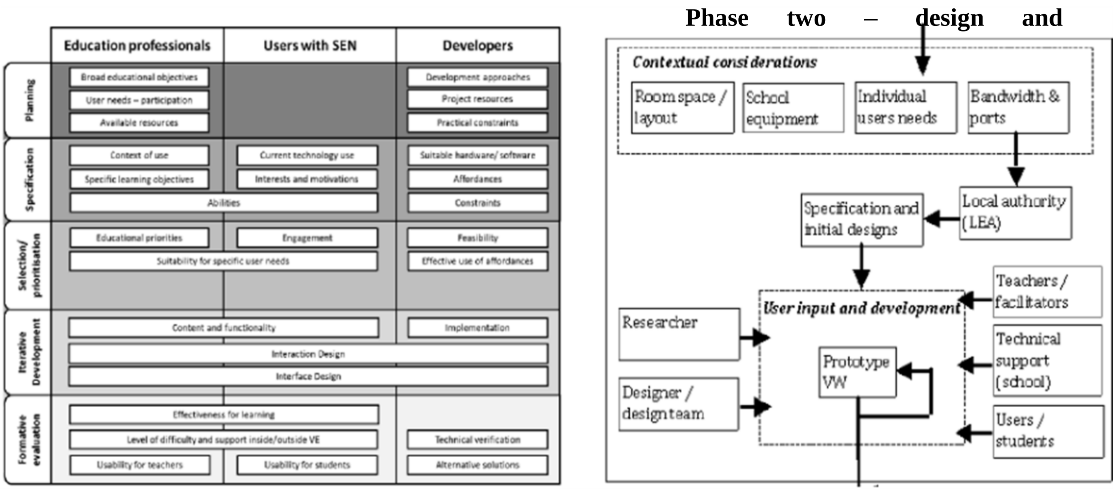

Figure 1. *Development of VR technology for autism education includes stakeholder involvement at different stages of design (left: Cobb et al., 2014) and contextual considerations for classroom use (right: Newbutt, 2013)*

3. REFLECTIONS AND RECOMMENDATIONS

In both of these projects we experienced positive response from teachers and pupils to the new technologies and applications developed. Both achieved successful implementation in the school environment *within the lifetime of the project*, although the procedure for this was smoother and there was less interruption to the normal routine of students in the VIRTAUT project. In both projects the completed applications were left in place in some participating schools and the researchers trained teachers to set up and use the technology. However, sustained use of the technology did not continue beyond the end of either project. This is not a new finding; many examples in the literature discuss factors affecting teacher adoption of new educational technologies and report issues related to teacher training, confidence in using new technology, technical support etc (e.g. Basak and Govender, 2015; Keengwe and Onchwari, 2009). Suitable and sufficient support for these issues is particularly relevant when new and complex technologies are introduced (Weiss et al., 2014) and it is important for projects to consider the whole school context, including infrastructure and support to new system implementation (Tearle, 2003). In other domains of VR applications, such a clinical assessment and rehabilitation, issues related to knowledge, skill and confidence of the clinician, combined with lack of equipment funding, and motivation of therapists and patients to use new technologies have been highlighted as barriers to VR implementation (Glegg and Levac, 2017).

Reflecting upon our own experiences and drawing upon the experiences of other projects reported in the literature, we consider how the framework should be further developed and modified to enable more successful technology integration in schools (Table 1).

Table 1. *Recommendations for further development of the framework*

Reflection	Development of the framework
Embedding the research/designer within the context of use provides a deeper appreciation of the school environment than obtained through external visits.	Identify additional contextual considerations to include a wider array of issues, some of which may be specific to individual classrooms.
A multi-disciplinary design team offers rich input to the development of new technology, but this must be carefully managed throughout the design process.	Integrate the two models shown in Figure 1 to show what input from different stakeholders informs and feeds into the design at each phase.

Teachers require professional development and support to confidently use technology in classrooms	Include the broader set of challenges related to training and infrastructure support for teachers and IT and technical
Strategies are needed to support sustainability of use; policy makers and school leaders need to consider supporting innovations for implementation of new technologies	Extend the framework beyond the current focus on collaboration with individual teachers for specific projects to encompass a wider systems perspective.
Similar barriers to implementation have been identified in research exploring other domain applications of VR.	Review and integrate relevant factors affecting implementation reported in other domain applications

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Using decision theory for analyzing enrollment in a scientific study in the health area

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ABSTRACT

This article explores the current literature about the factors that lead people to enroll in a scientific study in the area of health. Recruitment of participants has been shown to be a problem with the number of participants willing to participate decreasing widely. For this reason, it is important to understand how and why people make the decision to participate in a scientific study, in order to develop mechanisms that counteract this tendency. For that purpose, a review of current literature was conducted and the evidence was related with decision theory. The goal is to understand how the decision process to participate in a study occurs and which actions can be taken to maximize the recruitment process.

1. INTRODUCTION

One common problem in health research is the difficulty to recruit and maintain participants during all the phases of a study. Recent data suggests that participation rates among individuals of different ages, even those most represented in epidemiologic clinic investigation, fell into levels that can endanger some research areas (Galea & Tracy, 2007). Therefore, we are trying to understand the variables and mechanisms related to the recruitment process and the involved decision-making process to participate in such studies.

In the healthcare setting, high impact decisions that affect people's well-being and quality of life are often taken. In this area, emphasis on research has been growing and focuses essentially on experimental research (Sanders & Haines, 2006; Sim & Wright, 2000), or in other words, in the improvement and development of therapeutic strategies and rehabilitation. Financial investment has been important and substantial in areas such as drugs and vaccines. However, one of the main reasons that pushed research in health was the need of "evidence-based practice". This philosophy is one of the basis of decision making by the majority of health practioners, which is based in using therapeutic strategies that have been validated and their efficacy scientifically proven, instead of grounding their practice in personal experience, clinic intuition or more traditional proceedings (Sim & Wright, 2000). For this reason, "evidence-based practice" is directly related to research, as it does not depend on opinions, values, preferences or expectations. For this kind of research to happen, it is necessary to recruit people, given that most of research in this area is intimately related with the human being. Therefore, people have an important impact in this field of research and are also those who benefit from the health services, which we want to be the more efficient as possible. Thus, it is important not only to increase the amount of research, but mainly the proportion of people that enroll in studies (Salmon et al., 2007). This is an international priority (Lionis et al., 2004).

In the literature, there are several references about the difficulties and barriers faced when recruiting participants for scientific ends, among them we can mention the way possible participants are approached (Hewison & Haines, 2006) and belonging to a minority group (racial and ethnic minorities, elderly, children, rural residents, people with low socio-economical level) (Ford et al., 2008).

In this work, we reviewed the literature in order to understand which mechanisms/variables work as barriers/facilitators to the enrollment in scientific studies related to health. We aim to cross this information with decision theory in order to understand how we can increase chances of having success when recruiting participants.

2. BARRIERS TO PARTICIPATION

According to Ford et al. (2008), for a person to accept/refuse to participate in a clinic trial, he/she has first to be aware that it is happening (Awareness) and then needs to have an opportunity to participate (Opportunity). After having the opportunity to participate, the individual can look for information about potential risks and benefits of a possible participation (Acceptance/Refusal). This conceptual model also reports an association between specific factors and the decision not to participate, specifically; (1) Apparent physical pain/discomfort from participating in the trial; (2) Loss of control (uncertainty about group allocation during the treatment); (3) Nature of the intervention; (4) Time of intervention; (5) Salary loss (by missing work); and (6) Transport.

Interestingly, the number of people that agree to participate in a study is much bigger when they are approached directly by the researcher then when people have to take the initiative to participate and approach the researcher with that purpose (Hewison & Haines, 2006). The same authors criticize the actual recruitment approaches and suggest other practices highlighting some participants particularities. For example, many participants do not want a detailed explanation about methodological issues such as problems caused by biased samples. These authors also defend that people prefer to be sure that the research topic has quality and is relevant and judged by fair and impartial elements. Additionally, the contribution of participants must be valued and appreciated. Specific constraints for participation are: (1) Most of the times health research is a novel topic for many participants; (2) Few will understand its scientific basis; (3) Many people do not realize the importance of a high participation rate and can conclude that their participation is not necessary; (4) Erroneously assume that their participation is not useful because they consider that only 'typical' participants will be desired; (5) To have prior hostile preconceptions due to previous experiences or events related to research; and (6) Difficulties in reading, writing or walking.

Ejiogu et al. (2011) conducted a longitudinal study over 20 years to identify and rectify participation barriers in scientific studies in order to recruit and maintain participants during all phase of a study. The authors worked with a bi-racial sample (Afro-Americans and Non-Hispanics whites) with diverse socio-economical levels. Three barrier domains (individuals, community, and researcher and scientific), respective subdomains and solutions to overcome these barriers were identified. As second and third domains are not directly related with the individual, we will not discuss them, however, they have indirect influence when choosing to participate in a study. From the several subdomains, we emphasize the ones we particularly experience in our practice, such as transportation, economic constraints, behavioral & social factors. The solutions encountered for transportation were to provide free transport or neighborhood presence, flexibility and compensations for economic constraints, and none for behavioral & social factors. The conclusions focused in the main solutions found to recruit and keep minorities or economically poor participants during all the process: (1) Research hypothesis clearly communicated; (2) Provide a direct benefit to participants; and (3) Selection of a hypothesis that is directly relevant to the studied community.

Galea & Tracy (2007) elaborated a literature review to understand the reasons behind the decrease over time of participants' adherence in scientific studies. These authors identified four possible reasons that help to explain this phenomenon. The first is the proliferation of scientific studies, both academical and governmental, which we have witnessed in the last decades. The second reason is the decrease in voluntarism that contributes for lower motivation in volunteer involvement. The third cause is the fact a specific study might not bring any direct or immediate benefit to the participant. A fourth reason has to do with the own nature of studies, namely the ethical criteria and phases that constitute a study such as informed consent, several moments of intervention, long assessments and follow-up. All these reasons increase the tendency to people rejecting to get involved because they assume or feel that it is too much exhausting and will consume too much of their time.

Another systematic review by Ross et al. (1999) corroborates some barriers that recent studies have also identified. On their conclusions, the authors refer that additional demands from a study can influence the decision to participate or even lead to drop-outs. Problems like transportation or the costs associated were also identified as causes that lead to avoid participation, miss a session or drop-outs. In contrast, the authors observed that the most common motivation to participate is altruism. However, there are other factors that seem to contribute such as: (1) Counseling from someone important (familiar, close friend, wife/husband); (2) Recruitment by medical doctors; and (3) Good relationship with researchers.

3. DECISION THEORY AND UTILITY FUNCTION

Decision theory (for an overview see (Resnik, 1987)) is a research area that studies how individuals or groups of individuals make decisions. Almost everything that a human being does involves decisions. However, decision theory studies the situations where there are options to choose from, and these options are chosen in a nonrandom way. In this situation, the choices are *goal-directed* in the sense that they maximize the outcome utility. Utility is a measure of preference over an outcome. This measure can be objective (e.g. amount of money) or subjective (e.g. grade of satisfaction). We can divide the decision in three big groups: "decision under certainty", where the agent knows the consequence of his decision; "decision under risk", where the individual knows his decision will result in a given outcome with a certain probability; and "decision under ignorance", where the individual knows the possible outcomes of his decision but ignores the probability of each of them. Therefore. in this paper, we will focus in decision under ignorance as it is what happens when people accept or decide to participate on a health study.

There are several strategies to increase outcome utility with decisions under ignorance. One can value different aspects such as Maximin Rule, Minimax Regret Rule, Optimism-pessimism Rule and the Insufficient Reason Principle (Briggs, 2014). All them can produce different choices, and given we are under ignorance, there is no alternative that maximizes all the techniques. Hence, there is no obvious choice. The Insufficient Reason Principle seems to be the most reasonable to be used in this particular situation, since it is based on the principle that under ignorance different probabilities among the states (barriers/facilitators) are not evident. Therefore, we assume all as being equally likely. Anyhow, this principle can be seen as an attempt of making a decision under ignorance in a decision under risk. Laplace declared this principle as “reducing all the events of the same kind to a certain number of cases equally possible, that is to say, to such as we may be equally undecided about in regard to their existence, and in determining the number of cases favorable to the event whose probability is sought. The ratio of this number to that of all the cases possible is the measure of this probability, which is thus simply a fraction whose numerator is the number of favorable cases and whose denominator is the number of all the cases possible.”(Laplace, 2012).

To calculate the best decision, we did a weighted average multiplying the value of the item attributed utility by the item expected personal utility. Accordingly, the most likely choice must fall over the one that shows the highest value, meaning a higher utility. Therefore, we created a model case of a possible participant in a health research study.

3.1. Model Case

To test the choice between to participate or not to participate in a health research study, we created a model case attributing some characteristics that would be acceptable a male with 50 years to have:

- Male;
- 50 years old;
- Stable job with a 2500€/month salary;
- No familial obligations;
- Can freely manage his work time;
- Recent cancer diagnosis.

We have chosen 4 barriers and 2 facilitators, and associated utility values to each one. A prediction of personal utility values according to the profile of the case model were attributed (Table 1). These values vary between “0” and “1”, with 0.5 meaning a utility without impact. A value below this means a negative impact, and above means a positive impact. The further values are from 0.5, the bigger the impact that must be assumed. It should be noted that these values were attributed according to the profile created, meaning that is something very personal and that can change between different circumstances. For example, what is a barrier for one person can be considered a facilitator for another. After calculating the utility just with barriers (Ejiogu et al., 2011; Galea & Tracy, 2007; Ross et al., 1999), we got a value of 0.41 to “Participate” and 0.40 to “Not participate”. Hence, while the difference is minimal it still compensates to “Participate”. Next, we included two facilitators. This way, we should expect a large increase in the “To participate” ratio compared to “To not participate”. After we included the facilitators, the difference between the two values is more considerable, with 1.43 to “Participate” and 1.16 to “Not participate”, which makes the decision of participating almost 25% better than not to participate.

Actions		Participation		Non-participation	
		Item value	Item attributed value	Item value	Item attributed value
Barriers	**Wage loss**	0.1	0.4	0.1	0.5
	Without self-transportation	0.3	0.5	0.3	0.5
	Intervention time (time spent)	0.2	0.7	0.2	0.4
	Possibility of slight pain as a consequence of study participation	0.2	0.4	0.2	0.6
		0.41		0.4	
Facili-tators	**Financial benefit to cover costs and time spent**	0.8	0.6	0.8	0.5
	Research in new cancer therapies	0.9	0.6	0.9	0.4
		1.43		1.16	

Table 1. *Simulation of some possible barriers and facilitators identified by the literature related to the participation in health research. Each item was attributed a utility and an expected personal utility.*

4. CONCLUSIONS

Recruitment proceedings are part of science and not an administrative component. In order to contribute to health services development, recruitment proceedings need to reduce the factors that have the potential to lead possible participants to refuse participation in a study. Given that the decision to participate in research is probably determined by trusty perceptions, benefit, and justice, communication with possible participants should not be ignored. Communication should be robust and strategic, explaining why the use of personal information is important and needed for research, in order to promote higher participation rates.

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Mobile biofeedback low cost therapy systems for home, outpatient and institutional rehabilitation care

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ABSTRACT

Background and aims: The aim of the study was to verify usability of mobile biofeedback therapeutic system Homebalance in group-based therapy of patients with a diagnosis of vertebral algic syndrome as a substitute for individual therapy, to evaluate therapeutic effect of this type of group-based intervention and to evaluate effect on reduction of manpower requirements.

Methods: The study included patients with a diagnosis of vertebral algic syndrome in the subacute and chronic phases, who were hospitalized in Rehabilitation center Kladruby. 73 patients were included in the study. All patients received conventional individual physiotherapy (1:1 ratio) for 4 times per week and once a week they received group balance therapy with Homebalance, a system consisting of Nintendo Wii Balance Board and a tablet with developed therapeutic software for visual feedback, under a physiotherapist's supervision (1:7 ratio). The whole program lasted for 6 weeks. This group balance therapy consisted of testing and reference exercises using Homebalance (3 min), therapy with Homebalance (5 min) and independent exercise (15 min).

Results: The design of therapy was accepted across the patient group without occurrence of any undesirable side effects. A more significant improvement was achieved by patients who performed poorly at the initial examination and had a scoring record in the therapeutic game which was higher than the standard for a healthy population. There was an improvement of 11 seconds (p=0.0002) in patients who practiced for 3-6 weeks. Stability examinations showed improvement in laterolateral symmetry. A more significant improvement in posture was detected when visual feedback was given. Notable decrease of 86 % in manpower requirements was observed as a result of employing only one therapist in group-therapy training units.

Conclusions: Mobile biofeedback system Homebalance is easily usable and effective tool for group therapy. To make further recommendations and to set up therapeutic planning, it is necessary to carry out more detailed study with additional objective therapeutic trials as well as to provide larger patient population for subsequent data analysis.

1. INTRODUCTION

The incidence of vertebral algic syndrome (VAS) is increasing and high prevalence of such condition induces considerable economic costs (Ma et al., 2014). It is common cause of disability (Freburger et al., 2009). Back pain exacerbations are common reason for lost work days (Ricci et al., 2006). Group-based multidisciplinary biopsychosocial rehabilitation has been reported to be effective for the treatment of back pain (Dufour et al., 2010). Interventions utilizing gaming technologies report strong retention and adherence rates, reduced perception of effort and fatigue and increased enjoyment of exercise-related activities (Waburton, 2013). Coordination and stabilisation exercise programs have beneficial effect in the treatment of back pain (Searle et al., 2015).

The aim of this study was to verify usability of mobile biofeedback therapeutic system Homebalance in group-based therapy, to evaluate therapeutic effect of this intervention and to evaluate whether manpower requirements will be affected.

Homebalance is interactive mobile biofeedback low cost therapy system for treatment of balance disorders in home, outpatient and institutional rehabilitation care. It consists of tablet, Wii balance board (WBB) and therapeutic software providing game-like therapy (Stredova et al., 2017). After that, Homebalance can act as a virtual assistant therapist which renders motor learning more effective by providing exact tasks and giving visual feedback in real time. Thanks to this assistance, the physiotherapist can provide quality individual therapy to a larger group of patients at the same time. WBB is a valid tool for the quantification of postural stability (Holmes et al., 2013). The use of WBB and gamification of the therapy have positive effect on decreasing of vertebral pain (Kim et al., 2014).

2. METHODOLOGY AND DESIGN

The evaluation was carried out in institutional care at Rehabilitation center Kladruby (RUK) for reasons of critical assessment and massive Homebalance utilization. For the evaluation of Homebalance system, we used four sets in the group. Maximal number of patients in one group was 7.

The study included patients with a diagnosis of VAS in the subacute and chronic phases, who were hospitalized in RUK. We included patients with VAS, who were clinically stable, aged 18-60 years, with ability to maintain standing position for at least 20 minutes and ability to perform required exercise. A fundamental condition was the active cooperation of the patient and their understanding of the instructions. Inclusion in the group took place at the earliest after a 1 week stay in RUK and after training by a primary therapist during normal individual physiotherapy sessions. The exclusion criteria included blurred vision, severe cognitive impairment or psychiatric disorders, pregnancy, epilepsy and weight over 150 kg (maximum weight allowed by the manufacturer of WBB). All participants signed written informed consent before entering the study. This trial was approved by Ethical Committee of RUK. 73 patients (42 female, 31 male) of average age 58 years (SD 12) were included in the study.

Figure 1. *Therapeutic session.*

The interactive Homebalance system has been used during diagnosis and therapy. During training, the patient stands on the force platform and controls the game scene displayed on the tablet display by changing the position of their centre of gravity (Figure 1). First, the physiotherapist teaches patients how to control training scenes by using the correct movement patterns.

In the pilot feasibility study, before the therapy began, standard dynamic scenes were performed on the platform and a posture diagnosis of the patient was made. Based on the results of this, the focus and difficulty level of the therapy were then set.

Testing is performed in a position of uncorrected posture (placement of legs on the center of the platform at waist width) - spontaneous stance. Therapy is performed in a controlled = corrected postural position (activity of inner balance system, proprioceptive neuromuscular facilitation, corrected pelvis position, corrected head position, centering of shoulder blades, controlled deepened breath). The assessment of the patient is made using a statokinesiogram and is based on the achieved level of exercise, scoring record in the therapeutic games and the ability to maintain a corrected postural position.

The usability of described system in group-based therapy and adverse effects have been analyzed. Stability of quiet stance before and after the therapy was statistically evaluated, as well as time needed to complete game-like dynamic reference scene. Impact on manpower requirements was calculated.

3. RESULTS

The design of therapy was accepted across the patient group without the occurrence of any undesirable side effects. The average time required to complete the standard dynamic scene was 62 (SD 11,8) seconds for men and 65 (SD 18,1) for women during the initial examination. At the initial examination a total of five of the 73 patients had a time which was higher than the standard for a healthy population (Figure 2).

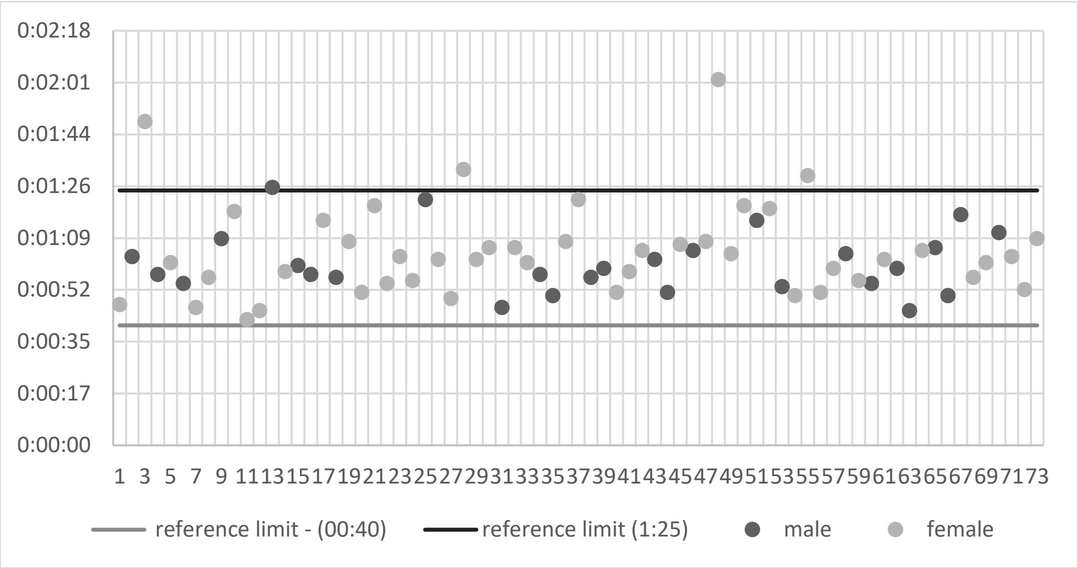

Figure 2. *Time required to complete the reference therapeutic scene*

During the initial examination, patients were observed in terms of their ability to reduce the length of time needed to meet the demands of the standard dynamic scene. The average improvement in scoring in the therapeutic game after the therapeutic intervention was by 11 seconds (p = 0.0002) (Figure 3).

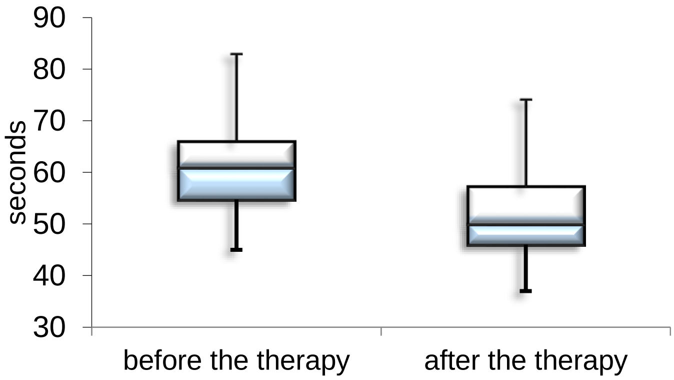

Figure 3. *Time required to complete the reference therapeutic scene before and after the therapeutic intervention*

A more significant improvement in time required to complete the reference game (the improvement of dynamic stability) was achieved by patients who performed poorly at the initial examination and had a scoring record in the therapeutic game which was higher than the standard for a healthy population. Stability examinations showed improvement in laterolateral symmetry. A more significant improvement in posture was detected when visual feedback was given.

The group-based intervention has been found feasible and preferred by therapists. With the utilization of 1 therapist in 3 x 30 minutes training units of group-therapy consisting of group of 7 patients (a total of 21 therapies), the number of therapists needed for regular individual therapy was decreased by 18 therapists, thus by 86% per one group of patients.

4. CONCLUSIONS

The design of therapy was accepted across the patient group without the occurrence of any undesirable side effects. Improvement in laterolateral distribution of weight and improvement in dynamic stability was observed after therapeutic intervention. The number of therapists needed for regular individual therapy was notably reduced.

The results of this evaluation lead to practical new application of the Homebalance system in group therapy, further bringing reduction of manpower and time requirements while maintaining therapeutic efficacy monitoring (supporting the introduction of this therapy as an alternative to individual therapy).

To make further recommendations and to set up therapeutic plan, it is necessary to carry out more detailed study with additional objective therapeutic trials as well as to provide larger patient population for subsequent data analysis.

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Designing for the deaf: The potential of technology supported social skills training interventions for d/Deaf and Hard of Hearing students

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ABSTRACT

Technology-supported social communication and pragmatics training for d/Deaf and Hard of Hearing (DHH) students is an important avenue of research. In this paper we describe some key challenges that DHH students face, the human centered design process used to uncover insights with stakeholders, and the potential of technology-based interventions to support development of social pragmatic skills. We further describe user experience considerations for DHH students, identified through discussions with subject matter experts, from a review of the literature, and identified through ongoing interviews with educators and parents, in addition to focus groups with teachers of the deaf.

1. INTRODUCTION

Deaf and Hard of Hearing (DHH) students face several challenges in the acquisition and development of effective communication and social skills. Over the past 30 years, the development of hearing device technology such as cochlear implants and early detection of deafness have contributed to significant progress in enabling DHH students to access sound. However accessing spoken communication is one step in developing effective interpersonal communication. Further steps include understanding the nuances of conversations and social interactions, which require considerable learning about self and others, and is a well-documented challenge for DHH students (Peterson & Siegal, 2000). The design, development and use of technology-based interventions to support social skill development in DHH students in an area of practice that has received limited research attention.

Increasingly sophisticated hearing technology has contributed to a majority of DHH students learning oral language and attending mainstream education settings. A key to success in these settings is having effective social-pragmatic skills (Luckner & Muir, 2001). Delays in language development are relatively common for DHH students compared to their hearing peers, particularly when the deaf or hard of hearing student is born to hearing parents. These delays in language acquisition have a substantial impact on theory of mind development and executive functioning; areas associated with the ability to attribute mental states to others, consider multiple perspectives and communicate with others effectively (Peterson & Siegal, 2000). These are also areas that students on the Autism spectrum experience significant challenges with.

Practical teaching of social pragmatic and communication skills is often needed, and strategies such as role-play are occasionally utilised by subject matter experts (SMEs) such as resource teachers of the deaf (Marschark & Spencer, 2003). However, due to finite time and resources available to each deaf student, technological support that students can access in a flexible way could provide valuable learning opportunities and reinforcement mechanisms. Such interventions could create a safe place for students in which to learn effective communication strategies, building their resilience in a way that also prepares them for meaningful engagement and more active involvement in social interactions within and outside the classroom. The potential of serious games to offer valuable learning opportunities in an intrinsically motivating way is discussed in detail by several authors (e.g. McGonigal, 2011; Walz et al., 2015) who conceptualise them as engaging mediums that can employ highly motivating strategies and mechanics such as choice, autonomy, rewards and feedback for effort and persistence, flexible identities and clear goals.

In this paper, we first present our findings from a literature search and formative consultations with subject matter experts. We then describe areas of social communication identified as important for consideration in the intervention, and discuss preliminary findings arising from primary data collected in interviews, and the implications for user experience design of the intervention. Finally, we suggest future evaluation through an iterative human-centered design process with resource teachers, teachers of the deaf and DHH students.

2. BACKGROUND

We conducted a structured literature search to provide an overview of the current state of the art in technology-supported social skill interventions for DHH children and young people. Due to a lack of results, we extended the search strategy to include interventions for students on the autism spectrum where the nature of the intervention was identified as being potentially relevant to DHH students. For example interventions dealing with Theory of Mind, executive function and effective social communication. Including this secondary user group of ASD students was theorised to be relevant due to studies, which have demonstrated that DHH students can have delays in these areas akin to autistic children (Peterson & Siegal, 2000).

The final search strategy was then specific to include in the search a game or AR/VR application(s) that had the primary goal of providing a social skills intervention for deaf or hard of hearing students under 21 years of age or people with an autism spectrum disorder. The search was carried out on the following databases: COMPENDEX (which indexes IEEE and ACM), EMBASE, MEDLINE, ICDVRAT archive, PsycINFO, Scopus and Web of Science. A detailed outline of the search strategy including the specified inclusion and exclusion criteria is available in Prospero using CRD42018092708 as the ID (Platt-Young & Hoermann, 2018).

Searching the seven databases and initial screening to remove duplicates and irrelevant papers resulted in 92 possible papers that met the inclusion and exclusion criteria specified in the search strategy (ibid.). The majority of the studies were found to have an ASD focus; very few are primarily focused on interventions for deaf or hard of hearing students. This suggests a paucity in the research into how technology-based interventions can best be designed for DHH students.

Necessitated by the relatively sparse information provided in the literature regarding guidelines for the design of technological social-skill and pragmatics interventions for DHH students, we consulted with subject matter experts including teachers of the deaf in mainstream school settings. SME feedback has identified several areas for exploration, which will be further researched in interviews and focus groups with resource teachers of the deaf, speech language therapists and parents. These areas are: conversational repair strategies, contextual barriers, self-advocacy, self-efficacy, and stigma. In addition peripheral areas such as: theory of mind, executive function, scaffolding and role-modelling, were also identified.

Stigma was identified as a reason for why low functioning students may be struggling in social pragmatic areas, due to a perceived lack of family acceptance of their hearing status and hearing accommodation usage. Family acceptance of the hearing status of a deaf child appears to be of critical importance in counteracting stigma. This is also reflected in the previous work of researchers who have investigated factors for DHH student success and resilience (Ahlert & Greeff, 2012; Luckner & Muir, 2001), and has been further confirmed in recent interviews and focus groups. An insidious form of stigma can also be low expectations of the DHH student to succeed in education settings.

Contextual barriers describe environmental factors impacting DHH students' ability to communicate effectively and participate in social interaction. Examples identified by resource teachers are visual stimulus and noisy outdoor environments which present significant challenges and can lead to frustrations. Pre-teaching clear communication strategies for dealing with interactions that occur outside the classroom was identified as important by teachers of the deaf, and one Resource Teacher of the Deaf (RTD) described a strategy where they would record the DHH student playing outside and discuss with the student behaviours that had occurred, in an effort to provide feedback relevant to the communication context and associated barriers.

Conversational repair strategies describe strategies that students take to correct a misunderstanding, provide someone with clarification, or to request clarification, for example by asking another to repeat or rephrase a question. One RTD referred to question skill training being of high importance in his work with DHH students. A lack of questioning and repair skills can significantly impact interactions with peers and DHH students are often specifically delayed in these areas (Yoshinaga-Itano, 2015).

Self Advocacy describes acting and speaking on one's behalf, and in discussions with educators regarding possible goals DHH students may have, a lack of goals or demonstrating self advocacy skills was attributed to language deficiencies. Self advocacy appears significantly linked to students' language and communicative skills, which has been demonstrated in research investigating self advocacy differences between hard of hearing (HH) students and hearing peers (Michael & Zidan, 2018).

Self-Efficacy is one's belief in oneself to accomplish a task and to take actions towards goals (Bandura, 1982). In primary data collected to date, educators have drawn attention to expectations of DHH students being too high or too low as being a possible factor for how attainable goals are for students, describing incremental learning as an optimal strategy for students. This would presumably be well accomplished through a game-based learning model that breaks larger goals down into manageable

Cawthon et al. describe in their review of research into the social skill development of deaf youth two main theoretical frameworks when considering social skills research: *socioemotional perspectives* that focus on behaviours and interactions, and *humanistic ones* that focus on personal qualities such as self-concept (Cawthon, Fink, Schoffstall, & Wendel, 2018). It is probable that near equal focus on both is needed in the intervention, as opportunities to practice communication skills and behaviours could reinforce a student's self-concept and belief in future success in social interactions. Both frameworks are important when considering a game-based learning approach, as game mechanics focus on behaviours and games additionally offer the opportunity to role-play and take on alternate identities.

The acceptance and feasibility of interactive video games in addressing pragmatics areas has confirmed by teachers and parents to be worthwhile. Respondents have their DHH students/children find games to be highly engaging, especially if they include rewarding feedback to provide the motivation needed to persevere if success was not forthcoming. Such mechanics could support self-efficacy development by providing an achievable goal. Captions and language modality considerations are also a recommendation for further research and implementation efforts.

3. FRAMEWORK

Human-centered and goal-directed design processes (Cooper, 2014) are employed in this project in addition to a Grounded Theory framework to define themes for the development of personas. Interviews are in progress with teachers of the deaf, resource teachers of the deaf, mainstream teachers and parents of DHH students. For reasons of privacy and anonymity, interviews with parents were deemed a more adequate method when compared with other methods. The plan is for interviews to continue until saturation can be achieved (Corbin & Strauss, 2008).

A variety of hearing accommodations and needs, different language and cultural backgrounds, varying reading ages, and different affinities with technology and abilities means that developing a first version of the game needs to be well thought out. For this reason, a continual and incremental development process is used in partnership with teachers of the deaf, some of whom are DHH themselves, offering valued input at various stages of the process.

Interviews and Focus Groups: Semi-structured interviews were identified as a primary method (Silverman, 2009) to gather SME input regarding social skills, social communication, user experience and technology considerations. These interviews focus on topics identified in SME consultations and include device use, gameplay and interface preferences, scenarios and general user experience considerations. Emergent themes are identified by coding interview transcripts, which further defines questions for future enquiry until saturation is achieved (Corbin & Strauss, 2008). The strategy implemented in the focus groups is the pursuit of a combination of reflective and ideation questions with teachers to elicit accurate personas and develop scenarios that are appropriate for student learning. Focus groups with resource teachers of the deaf, teachers of the deaf, mainstream teachers and speech language therapists are ongoing, and two focus groups, one with two teachers of the deaf in a satellite class within a mainstream school (both hearing), and one involving three RTDs (one hearing and two deaf) have been conducted. Initial findings highlight the importance of role play, explicit teaching of repair strategies, d/Deaf role models, interactivity and language skill development for pragmatic interventions.

Personas and Scenarios: Personas are employed to translate abstract information into a tangible research tool for the design effort and are particularly useful in an area such as this, where there may not be an established paradigm and in an effort to limit design assumptions and bias (Cooper, 2014; Pruitt & Grudin, 2003). Scenarios are two-fold in the project, describing interaction scenarios between end users of the game and the interface, and scenes that users can role-play that are illustrative of communication situations that provide valuable learning experiences. An example of a possible scenario is that of sports activity, as this was identified in interviews with parents and teachers as a common example of where communication breakdowns regularly occur. Personas and scenarios will be validated with resource teachers, as these individuals are highly knowledgeable about the target users and several are DHH themselves so they have a unique perspective that will assist in with the refinement.

User Experience Workshop: Low-fidelity concepts will be evaluated with DHH students between ages 6-12 in a user experience workshop, as this is the hypothesised age group most likely to benefit from the intervention given the expectation for students to be independent learners during secondary school. The idea is to view DHH students as co-design partners by their inclusion as testers (Guha, Druin, & Fails, 2008) using the user experience workshop as an opportunity to collect their recommendations and perspectives.

4. CONCLUSIONS

In this paper we have provided background information regarding pertinent areas of effective social communication and outlined the potential of technology-supported pragmatics training for DHH students. Through consultations with subject matter experts including teachers and parents we have identified key domains where technology could play a role in fostering social skills development. Focus groups and continued interviews with teachers of the deaf are suggested as a next step to prepare personas and scenarios in order to establish a design framework that further informs the development of effective technological interventions.

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Virtual shopping: Acceptance of immersive virtual reality in the diagnostic of memory deficit in elderly

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ABSTRACT

Memory decline represents a major cognitive problem associated with various neuropsychiatric and neurological disorders and physiological aging. A drawback of classic neuropsychological diagnostic and remediation tools, often applying pencil-paper approach, is the lack of ecological validity. Virtual reality represents a useful tool linking simulation of real world environments with precise control of stimuli and detailed behavioural recording. VR is typically presented in a less immersive form as a desktop application, or with more advanced technologies such as the head-mounted displays (HMDs). Both alternatives have certain pros and cons, but the role of immersion for the diagnostic and/or therapeutic use and acceptance of these alternatives in elderly is still unknown. In this pilot study, 32 cognitively healthy seniors performed in the virtual Supermarket Shopping Task (vSST), focused on declarative memory assessment, using both platforms (desktop and HMD) in a counterbalanced order. We compared their results in terms of cognitive performance and subjectively evaluated usability of the applied device. According to the preliminary results, the participants performed worse in terms of memory recall using HMD and the application usability did not differ significantly between the two platforms.

1. INTRODUCTION

Cognitive deficit is a core symptom of psychopathology in various neuropsychiatric and neurological disorders and is also a crucial component of physiological aging. Declarative memory represents the most common target of subjective complaints in elderly (Rönnlund, Nyberg, Bäckman, & Nilsson, 2005) and a core symptom in Alzheimer dementia (AD). Early diagnosis of cognitive decline can lead to well-timed interventions, which can delay the progression of the impairment and development of mild cognitive impairment (MCI), AD and other types of dementia (Gates, Sachdev, Fiatarone Singh, & Valenzuela, 2011). Classic paper-pencil neuropsychological methods applied for diagnostics and treatment are often criticized for their lack of ecological validity (how the experimental settings approximate the real world) (Neisser, 1978). Thus, there is an increasing interest in using realistic virtual reality (VR) in diagnostic and remediation of cognitive deficits. There is however an ongoing discussion about the importance of immersion in VR serious games. Immersion is technical feature of VR, which strengthens the feeling of being present in the virtual environment (VE). The level of immersion is increased by reducing real world sensations, interacting with elements of the VE and its multimodal nature (Slater & Wilbur, 1997). Simplified, less immersive presentation of VR can be achieved by desktop presentation on the monitor screen, while more immersive VE can be presented with head-mounted displays (HMDs). To our knowledge, only few studies compared the role of visual immersion in VR cognitive tasks. Previous studies assessed the role of immersion in spatial orientation (Sousa Santos et al., 2009) or in memory recall (Harman, Brown, & Johnson, 2016). As the reported results are not conclusive and the VR technology is rapidly changing, more extensive research is needed. In this paper, we would like to present our pilot study comparing impact of level of immersion on acceptance and cognitive performance. Using intra-subject design, we focus on healthy aging population performing VR-based memory test - virtual Supermarket Shopping task (vSST). The desktop version of vSST has been already tested in assessment of memory deficit in chronic schizophrenia patients in comparison to healthy young adults (Plechata, Fajnerova, Hejtmanek, & Sahula, 2017).

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2. METHOD

2.1 Participants

Thirty-two 'cognitively' healthy seniors without psychiatric diagnosis (13 males and 19 females) were recruited for the pilot study. The database of healthy aging respondents from the Department of cognitive disorders of the NIMH was used for the recruitment. The average age in the group was 69.9 years ranging from 60 to 91 years (males=70.4±7.0, females=69.9±7.1). Three of the participants had education level 2 (vocational school), 13 subjects had education level 3 (high school) and 16 participants finished university degree (education level 3).

2.2 Design

The participants were tested in two variants of the vSST (using two different platforms) during a single 1-day session: 1) **Desktop** version (less immersive form) was presented on a monitor screen and used keyboard and mouse as controllers, and 2) a more immersive form presented using **HMD** (HTC Vive virtual glasses) (see Figure 1B). The order of vSST versions was **counterbalanced** (Figure 1A). Between and after the assessment participants filled short questionnaire presented on PC screen. The whole session duration was about 2 hours with breaks.

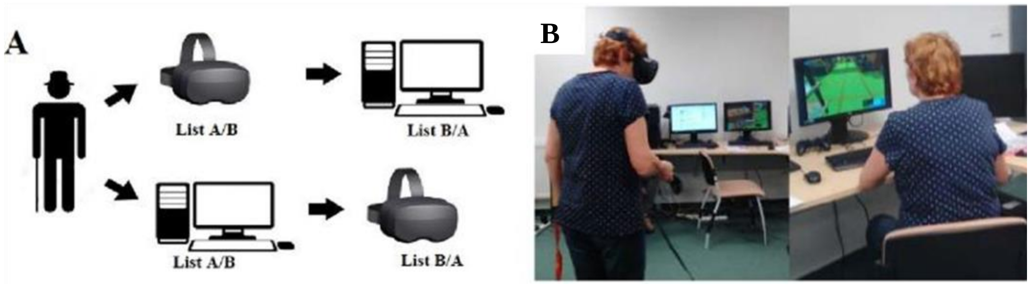

Figure 1. Study design. The scheme of the counterbalanced order of platforms in the experimental session (1A). A participant tested in HMD version (1B left) and desktop version of vSST (1B right).

2.3 The virtual Supermarket Shopping Task (vSST)

The virtual Supermarket Shopping Task was specifically designed for diagnosis and remediation of declarative memory deficit in ecologically valid environment using Unity game engine software (https://unity3d.com/). The target is to remember shopping lists which are presented to the participants and to collect the remembered items from the virtual supermarket. The vSST has 4 levels with increasing difficulty (for 3, 5, 7 and 9 items on the list). We used two sets of lists (A and B) that have been **counterbalanced** between individual platforms. These list variants were proved as comparable in terms of difficulty in previous research (Plechata et al., 2017). Prior to the beginning of the assessment the subject had certain amount of time (4 minutes using monitor, 10 minutes using HMD) to familiarize with the VE and system controllers. After the exploration phase, the shopping list was presented to the participants in the Acquisition phase. Consequently, the 3-minutes long Delay phase was presented, during which the participant was instructed to play visuospatial game called LEU Brain Stimulator (http://www.leubrainstimulator.com/). During the consecutive Testing phase the subject was supposed to enter the VE again and find and pick up the remembered items from virtual supermarket. For more details on vSST procedure see Plechata et al (2017).

2.4 Usability questionnaire

The questionnaire consisted of 4 parts: 1) demographic information and previous experience with PC and HMD, 2) usability of the vSST presented in HMD, 3) usability of the vSST in a desktop form, 4) comparison of the vSST task presented using two platforms (desktop and HMD). The questions focused on intelligibility of the instructions, usability of input controls, spatial orientation, preference of the platform and enjoyment from the game and were inspired by common usability questionnaires. The participants answered questions on a 5-point scale (ranging from 1/strongly disagree/ to 5/strongly agree/).

3. RESULTS

3.1 vSST performance

To compare participants` performance (number of errors) in desktop and HMD versions of vSST and possible effect of platform order, we applied GLM analyses with ANOVA for repeated measures with the following factors (platform* platform order* number of objects to be remembered). The analysis showed significant simple effects of 1) **platform** - benefiting desktop presentation in comparison to HMD (F(1,30) = 14.2277 , p < 0.001) and 2) **number of objects to be remembered** - difficulty level ((F(2,30) = 66.0706, p < 0.001). No effect of platform order or any significant interaction of individual factors was identified (p>0.05) (see Figure 2).

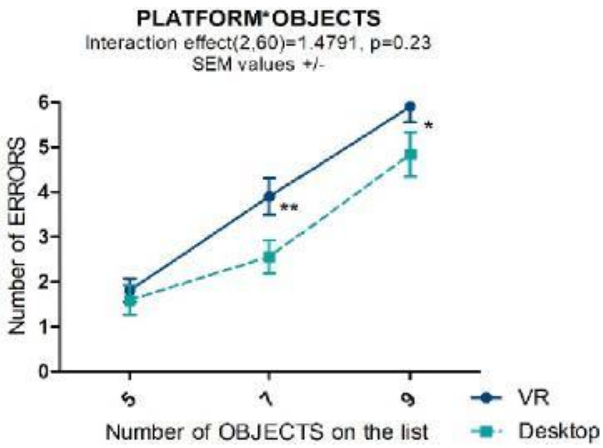

Figure 2. *Graph displaying number of errors in vSST according to the platform applied.*

Because of the non-normal distribution of the data, the Wilcoxon signed-rank test was used as post-hoc test to specify the effect of platform in individual difficulty levels of the vSST task. As you can see in Table 1, participants made significantly more errors in HMD vSST for 7 items (p=0.005) and 9 items (p=0.03) on the shopping list. Importantly, the difference in time spent fulfilling the vSST task was not significant between HMD and Desktop platforms.

Table 1. *Table displaying number of errors in vSST for individual platforms.*

Number of objects on the list	Mean of errors (± Std.Deviation)		HMD*Desktop	
	HMD	Desktop	Z	sig. (2-tailed)
5 objects	1.81 ± 1.45	1.59 ± 1.85	-	0.208
7 objects	3.91 ± 2.32	2.56 ± 2.11	-	0.006**
9 objects	5.91± 1.97	4.84 ± 2.80	-	0.05*

3.2 Usability Questionnaire

For comparison of the two versions of vSST presentation (platforms) in terms of input controls, intelligibility, preference, pleasantness, enjoyment and spatial orientation, we used the Wilcoxon signed-rank test. One respondent was excluded from the analysis due to technical problems with recording of responses (sample N =31). Table 2 shows there is no significant difference between the two platforms regarding application usability.

Table 2. *Table displaying the results of usability questionnaire for individual platforms.*

	Platform	Mea	Std. Deviatio	Z	sig. (2-tailed)
Input controls	HMD	3.03	1.38	-0.99	0.32
	Desktop	3.52	1.26		
Intelligibility	HMD	2.74	1.37	-1.29	0.20
	Desktop	3.35	1.33		
Preference	HMD	3.23	1.48	-0.44	0.66
	Desktop	2.9	1.38		
Pleasantness	HMD	3.16	1.34	-0.20	0.84
	Desktop	3.1	1.38		
Enjoyment	HMD	3.26	1.32	-0.64	0.52
	Desktop	2.97	1.25		
Spatial orientation	HMD	3.06	1.53	-0.70	0.48
	Desktop	3.32	1.25		

4. CONCLUSIONS

According to the reported results, the performance in vSST was different for individual platforms with various level of immersion, benefiting the desktop presentation over the HMD. Participants made significantly more mistakes while encoding 7 and 9 items on the shopping list using HMD device in comparison to desktop vSST variant. Previous studies also reported poorer cognitive performance using HMD (Sousa Santos et al., 2009). However, in terms of memory performance, more recent study showed in contrary to our results improved ability to recall information using HMD (Harman et al., 2016). Importantly, the difference between desktop and HMD platform was not significant in terms of usability, even though previous studies reported HMD as more intuitive and enjoying (Sousa Santos et al., 2009), for which we found only non-significant trend. Our results are in accordance with the study by Rand et al. (2005) that compared performance of two group age in rehabilitation tasks focused on motor and cognitive functions using HMD and desktop versions. According to this study, the cognitive performance was superior in desktop version for both age groups, but the older participants felt higher sense of presence in HMD and preferred HMD version more than the younger respondents. The observed discrepancy of our results with previous findings could be due to specific characteristics of the group of elderly (such as lower mental flexibility and willingness to use modern technologies). In order to confirm the obtained findings, it is therefore necessary not only to enlarge study sample of healthy elderly but also to add comparison group consisting of young adults. Moreover, the possible role of participant's motor abilities should be addressed in future studies as the two platforms require different level of motor response (participants were seated during the desktop activity but were standing during the HMD activity).

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Design, development, and evaluation of a novel mindfulness-supporting VR device

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ABSTRACT

Mindfulness is a meditation technique that has been shown to have a positive influence on the quality of human life in both sickness and health. The goal of the current research is to create an application in a virtual reality that facilitates mindfulness skill in a fun, interactive, yet effective way. The unique combination of a virtual reality (VR) scenario presented using 3D glasses with biofeedback (BF) will make mindfulness techniques easier to apply. The application created should support neuro-cognitive functions essential for psychological resilience and well-being. The effectiveness of such training will be subsequently verified via randomized controlled study.

1. INTRODUCTION

Growing excitement for electronic health applications, as well as increasingly more affordable VR systems has provided a promising opportunity for the development of novel devices promoting mental health. Mindfulness based techniques are applied in treatment of neuropsychiatric disorders (Goyal et al., 2014) and draw broad scientific interest due to their effect on cognitive functions (Lippelt et al., 2014).

One of the core features of mindfulness training is related to the ability to bring one's attention back to breathing every time the mind starts wandering. This implies that mindfulness requires attentional and emotional regulation strategies, which in turn require extensive training. VR devices and mobile applications designed to facilitate mindfulness have shown to increase relaxation and the sense of presence (Kosunen et al., 2016), but they often fail to facilitate attentional and self-regulation training. In our project, we utilise knowledge derived from cognitive-neuroscience in order to identify and support the mechanisms underlying meditation.

Importantly, different meditation techniques engage distinct attentional processes and affect cognition differently. Lutz et al. (2008) distinguish between two broad styles of meditation: focus-attention meditation (FAM), which requires a single focus of attention (such as on one's breathing) and open-monitoring meditation (OMM), which requires broader non-judgmental awareness (Lutz et al., 2008). Because our system aims at naive meditators (for which focusing is often easier), we consider FAM first. The level of difficulty between OMM and FAM is based on empirical observation from our lab data (Lippelt et al., 2014).

Besides meditation, simple paced breathing practices known as Pranayama were shown to have positive effect on cognitive functioning. Simple respiration practices generally involve inhalation and exhalation of air at a predetermined rate that is different from the regular breath cycle. Even short Pranayama exercises showed immediate effects on complex processes such as cognitive control and working memory (Yadav and Mutha, 2016). Furthermore, benefits of slower paced breathing had immediate positive effects on physiology, namely elevated activity of the parasympathetic nervous system, supporting autonomic regulation, leading to higher HRV and lower blood pressure (Lumma et al., 2015). Additionally, the coupling of respiratory and cardiac activity leads to the regulation of fronto-limbic functions, providing the down-regulation of negative affect, and enhancing cognitive control (Gothe et al., 2013).

However, keeping one's focus on one's breathing rhythm without mind wandering is challenging, in particular for naive meditators or in hectic office environments. VR facilitated meditation can be useful to shield meditators from visual and auditory distractors while immersing them in relaxing artificial environments. Recent studies show that VR-enhanced meditation increases the feeling of presence (Kosunen et al., 2016; Chittaro and Vianello, 2014). We aim to further promote immersion by introducing breath biofeedback in combination with an avatar model. A breathing-synchronized avatar induces visual-respiratory synchrony, necessary for the induction of subjective body ownership. This identification with the avatar enables the manipulation of the embodied state by manipulating the avatar features (feature migration) (Ma and Hommel, 2015). Ongoing research serves as a first pilot study to evaluate the interactive VR application, facilitating the practice of FAMn, and deep breathing. An important part of our research is to find the best design and the most suitable interface to support future users. We will investigate how this application can affect mental health, physiological and cognitive functions of healthy participants and psychiatric patients.

2. METHOD

2.1 Experimental Design

In the current research we aim to develop and validate the VR meditation device by investigating the added value with increasing complexity of the VR design. This will be done by means of qualitative comparison studies (within-subject design, N=60), in order to establish the optimal parameters of the virtual environment and provide maximum engagement. Participants will meditate shortly with every game variant of the tested parameter and evaluate their experience during each setting type by the means of questionnaires. We will assess and compare the effect of several parameters (with hypothesized increasing effectiveness) using various combinations of visual presentation and feedback methods: Pranayama breathing according to a monitor visualisation (1); pranayama breathing with head-mounted display (HMD) headset (2); the reinforcement of breathing frequency by biofeedback using HMD (3); the reinforcement of breathing by biofeedback and synchronization with avatar using HMD (4)

2.2 Materials

A set of four questionnaires will be used to evaluate the participants' mood and subjective experience with each variant of meditation game: (i) The Spielberger State-Trait Anxiety Inventory (STAI-6; Marteau & Bekker, 1992); (ii) The Affect Grid (Russell, Weiss & Mendelsohn, 1989); (iii) The Flow Short Scale (FSS; Rheinberg, Engeser & Vollmeyer, 2002); (iv) The State Mindfulness Scale (SMS; Tanay & Bernstein, 2013)

**Only a subset of questions was selected from the FSS and IMI*

2.3 Apparatuses

The person's breathing signals (respiration rate and effort) are recorded using a Vernier GO respiration belt, then communicated via Bluetooth to computer. The Biosignals are processed in order to affect the game mechanics of the Virtual Reality experience in real time. The HTC Vive head-mounted glasses device is used for immersing the user into the VR experience, providing accurate tracking of the person's head movements. The visual and auditory shielding characteristics of a VR environment allow the users to quickly engage in the experience (see Figure 1).

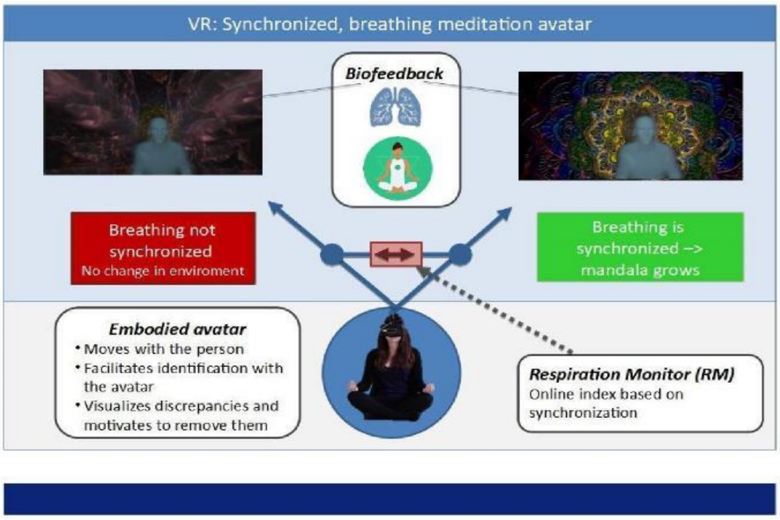

Figure 1. *The figure demonstrates features of presented VR application. Based on the outcomes from breathing biofeedback, users are rewarded if synchronizing with given rhythm of breath. Reward is shown as growing and multiplying mandalas, and/or changes in the expression of avatar.*

2.4 Procedure

After giving informed written consent participant will be asked to fill in the questionnaire assessing current mood state and anxiety level (STAI-6). We will also ask the participant to indicate his/hers experience with meditation. Next, 2-minute baseline recording will take place before the meditation exercise (making sure the respondent knows how to control the device). Participants will then engage in 7 minutes meditation exercise (one of the four – order counterbalanced). After each meditation exercise, respondent will be ask to fill in remaining questionnaires (FSS, IMI, SMS) and STAI-6 for the second time to assess the immediate effect of the exercise on respondents' mood and anxiety.

During this VR facilitated meditation (see Figure 2), a person will wear respiration belt and VR glasses and see a virtual environment with meditating avatar and will be asked to synchronize breathing cycle with the avatar's wings. The synchrony will be determined by continuous monitoring person's breathing through respiration biofeedback belt. These data will be fed back into the VR system, which in return increases the size of the mandala displayed behind avatar whenever participant achieves to synchronize. Furthermore, person-avatar synchrony will induce a further change in avatar's physical features that will become more positive (e.g., the smile).

Figure 2. *Participant in process of training with presented virtual reality application in interaction with breath bio-feedback and the photograph of the Vernier respiration belt.*

3. CONCLUSIONS

In this project we aim to develop VR-enhanced FA meditation training in accordance with scientific literature. This will be achieved by a unique combination of guided pranayama breathing exercise coupled with respiration biofeedback (using various sensors) and applied in an immersive virtual reality environment. We hope that this device will be effective in reducing stress, enhancing cognitive control and providing autonomic resilience.

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A new generation of the computerized Visual Spatial Search Task (VISSTA) as an authoring tool for rehabilitation assessment and intervention

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ABSTRACT

Individuals with visual impairments following brain damage are constantly facing challenges to achieve an independent life, primarily due to deficits in visual spatial perception and search skills as well as slow information processing. Given that these skills are critical for everyday tasks, we investigated the evolution of a computerized platform of Visual Spatial Search Task (VISSTA) as an authoring tool that can easily be implemented by clinicians for the assessment of visual spatial skills and speed of information processing. This paper aims to present the new version of the tool and results of a feasibility study conducted using the new authoring tool aimed to examine its design and ease of use. Participants included eight healthy young individuals.

1. INTRODUCTION

Attention is often a precursor to several neurological and cognitive functions. Impairments in visual spatial attention following brain damage thus affect the ability to function in many aspects of daily living (Katz 1999). Visual search paradigms usually provide a target that is defined either by its separate features or by their conjunction (Treisman & Gelade 1980). A typical conjunctive search task includes serial search and decision making of whether a prespecified target is embedded in an array of distractors, each of which share one or multiple features with the target (Shen 2003). On the other hand, a feature search involves identifying the prespecified target amongst distractors that pop-up from the target due to their unique visual features such as color, shape, orientation or size (McElree & Carrasco 1999). These two paradigms have thus been used extensively to examine characteristics of normal spatial attention mechanisms (Nakayama & Joseph 2000).
Search efficiency is examined by the response time of the participant to a set exposure time as well as their accuracy in identifying the target.

Clinicians typically use paper and pencil tests to assess visual spatial deficits. These test usually do not impose greater attentional demands as those that occur during everyday activities usually because they do not impose time restrictions and do not record reaction time. This is true especially in cases such as Unilateral spatial neglect (USN) which has been shown to be a real challenge for rehabilitation professionals to properly detect and characterize using conventional tests (Ting 2011). Recent studies have shown that participants doing well on conventional paper-and-pencil tests showed residual deficits when more complex functional tasks were employed (Dvorkin 2012). To address these concerns Bar-Haim Erez and her colleagues developed a computerized visual search test and training program (VISSTA – Visual Spatial Search Task) (Bar-Haim Erez 2006, 2009). The software tool employed both feature and conjunction search principles to assess detection rate and reaction time.

Performance on VISSTA differentiated between people with and without USN both in the feature and conjunction conditions indicating that USN is related to a severe attention deficit. Moreover, it was significantly correlated with difficulties in daily activities encountered by people with USN (Bar-Haim Erez 2009). The clinical usefulness of the VISSTA was also shown in a study where performance was correlated with driving in a simulator

(Kizony et al., 2005). Based on these studies it was suggested that the ability to add auditory distractions as well as change the stimulus to be more relevant to daily life (e.g., identifying face among other faces) would enable clinicians to assess visual search and attention, using a sensitive and more ecologically-valid tool.

The primary goal of this study was to evolve VISSTA into an authoring tool so that clinicians can easily vary task stimuli and other parameters such as segmentation into different visual zones as well as lateralization of stimuli. The tool was designed to provide the user to easily employ unlimited range of visual stimuli such as pictures, text, symbols by simply placing them in a folder within a pre-set directory on the computer. The study also provides results of a pilot test aimed to examine the design and ease of use of the new authoring tool.

2. Visual Spatial Search Task (VISSTA)

The computerized visual search test and training program VISSTA (Bar-Haim Erez, 2006) was developed to assess feature and conjunction search modes in individuals with brain damage. In the feature mode subjects were asked to detect a visual target which differed in color from a group of simultaneously presented distractor stimuli (ex: red circle is target whereas blue circles are distractors). In conjunction mode, subjects were asked to detect the same visual target as shown in feature mode, however in this case there were two types of distractor stimuli each sharing one primary feature of the target stimulus (ex: red circle is target and blue circle and red squares are the distractors). The primary disadvantage of using this system was it ran very slow due to a very old backend library which also made it difficult in adapting the software to new changes in stimulus presentation. For example, creating new visual stimuli packages was not a straightforward process and involved technical assistance. In addition, modifying the software to include new functionality such as random audio distractors were a tedious task.

2.1 Evolution of VISSTA

In order to address the limitations mentioned above, we redesigned the full software to make it into an authoring tool that can be easily used by clinicians. The figure below demonstrates the user interface for selecting stimulus packages as well as defining stimulus settings (Figure 1). The stimulus packages are created by gathering all pictures in a folder and placing them in the program data directory which reads them in real-time. The clinician thus does not need to configure anything other than creating the folder and placing the desired stimuli pictures within them. The program processes and optimizes the images automatically to make sure they are rendered in the correct resolution, including making changes to the alpha channel if required. Hence the clinician can use pictures of any resolution and file format. Some examples of these visual stimuli are show in Figure 2. The program requires pictures with no stimuli to have the letter “Q” anywhere in the filename so that it can automatically determine the accuracy of the responses when running the simulation. If the clinician wants to test a particular quadrant, they can label the pictures accordingly (LL – Lower Left, UR – Upper Right etc.). You could also label the pictures based on the distractors you have, for example 4, 8, 12 etc. This allows the clinician to easily create multiple folders with different stimuli which can then be conducted in a sequence selected during that session (Figure 1). The revised software also implements an SQL database to allow for the data to be structured and accessed easily through the user interface.

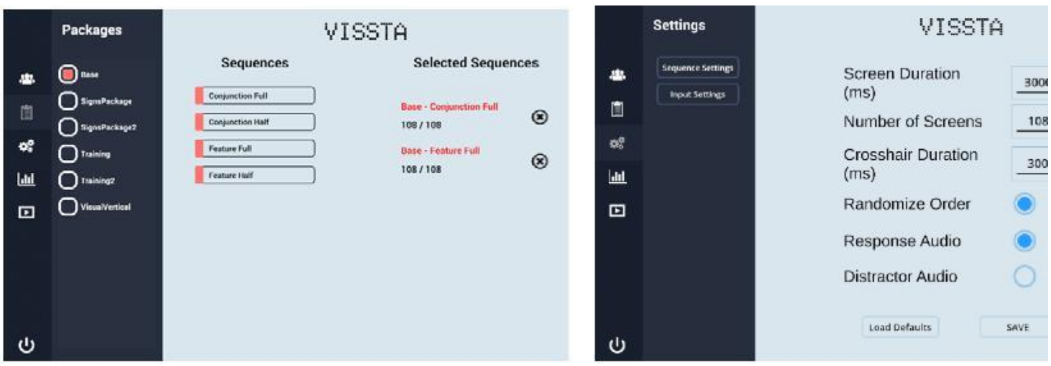

Figure 1. *VISSTA User Interface. The list of packages shown in the left figure represents the directory structure on the hard disk. Adding a new package involves creating a new directory whose name will be populated in the packages section once the program loads. The different settings available to the user are shown in the figure on the right including the number of screens and the duration of the screen.*

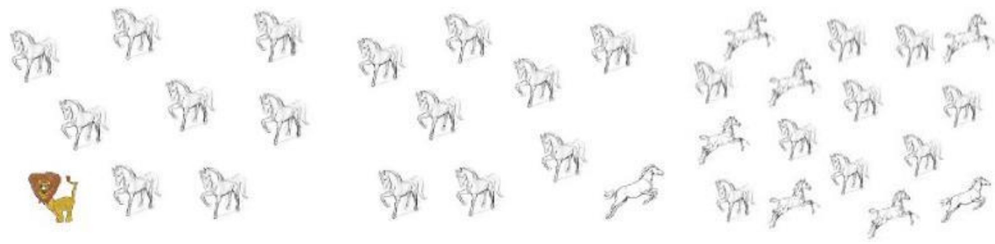

Figure 2. *VISSTA Stimulus Screens. The different screens represent the various ways in which both feature and conjunction-based search can be applied in VISSTA. The clinician has to gather the pictures and place them in a directory to use them in the application.*

2.2 Pilot Study

We tested the base package of the study in 8 healthy young individuals. The base package was developed based on Treisman and Gelade feature theory, which is comprised of two main conditions; feature and conjunction search, 108 screens are randomly arranged with variations of location of target, number of distracters, side of the screen, etc. and approximately 20% of the screens are without target (only distracters) (Bar-Haim Erez 2006). Subjects were asked to detect the same visual target (red circle), among two types of distracters (blue circles and red squares), the target differed from the distracters by at least one primary feature (e.g., color or shape) but was similar on the other feature. The target appeared randomly in one of 20 predetermined locations (5 targets on each quarters of the screen: right / left; up / down) and 5 screens without targets. The distracters appeared randomly on both sides of the screen. The location of the target and the set-size of distracters varied (from 3 distracters to 23). Thirty percent of the screens were without target (presenting only distracters and termed 'catch trials'), overall there were 108 screens (Bar-Haim Erez 2006).

For the pilot study, the conjunction condition was used. The subjects were required to press one button as soon as the target was detected and another button if no target was detected. Each screen appeared for 3000 msec regardless of participant's response. Reaction time and success rates were measured. The participants were seated in front of the monitor (size 17inch) at their arm length distance. All the participants went through training on the computerized tests to make sure they understood the instructions and can perform the two tasks. The Trail Making Test part B (Reitan 1995) that assesses visual search and shifting of attention was administered as well.

3. RESULTS AND CONCLUSION

To date, 8 young adults (3 women) aged between 25 and 32 years (mean± SD 27.5 ±2.3) participated. Their mean rate of success was 97.6 % (SD=2.3) and mean reaction time was 670ms (SD=66ms) indicating a high level of performance. Their high-level performance was also indicated in their performance of the Trail Making Test part B (43.6 ±7.1sec).

The researchers were able to operate the software easily while adapting the number of screens and type of stimulus. This ensures that the software can be used by clinicians for assessment as well as training of visuospatial skills as well as the speed of processing.

The software is regularly updated based on feedback from clinicians and researchers. Our future goal is to keep simplifying the user interface while making the backend robust to constant modifications based on clinical goals. In addition, we aim to conduct a study with a larger sample of healthy and clinical populations and use usability questionnaires to receive feedback from clinicians and users.

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Reducing clinical subjective discrepancies in evaluation of clinical technology using objective measures

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ABSTRACT

Technology designed for clinical use requires validation before it can be adopted by healthcare services. Clinicians are the best evaluators we have to determine the suitability of new technology. However, our results show that clinicians can have a low level of agreement when assessing the performance and suitability of technology. Thus, solid gold standard measures are very much needed for the adoption of new clinical technologies. Although further research is required to determine the factors for these discrepancies, we hypothesise that objective measures can aid decision makers in their evaluation of clinical technology and improve inter-rater agreement.

1. INTRODUCTION

New technology designed for clinical use requires clinical validation before it can be used within healthcare services. Our research looked at the inter-rater agreement among physiotherapists rating the suitability of a depth-sensor camera, that tracks a user's joint positions, intended to assist stroke survivors with their rehabilitation exercises through analysis and feedback. Given that many stroke survivors are expected to perform daily exercises at home unsupervised, technology-based rehabilitation systems could provide a motivating and safe environment for exercising. The aim of the physiotherapists was to determine whether the skeletal joint positions from the depth-sensor was accurate enough to enable an acceptable automatic assessment of the patient, and therefore accurate feedback to encourage correct exercise rehabilitation. Although clinicians are the best evaluators we have for assessing new clinical technologies, it is important to determine how accurate these assessments are to ensure a robust and fair evaluation.

Our results show a low level of agreement among physiotherapists rating the performance of the technology in a clinical stroke rehabilitation context. Although the factors causing the discrepancies have not been established (for example was it due to an insufficient rating criteria and/or lack of task training or experience of the physiotherapist), it is hypothesised that providing clinical evaluators with objective measures will likely reduce subjective discrepancies and improve inter-rater agreement. Objective measures would need to be established for the specific technology and clinical use case but would usually provide a quantifiable measure of error.

2. LITERATURE REVIEW

This section provides a brief overview of literature evaluating the inter-rater agreement among clinicians assessing patient performance. Barth et al. (2017) reviewed studies on inter-rater agreement in evaluation of disability assessed by medical experts. They found that there was an indication of high variation in judgement. They highlighted a need for the development and testing of instruments and structured approaches to improve the reliability in expert evaluation of disability. Our results support this conclusion and highlight a need for more reliable evaluation methodologies for technology intended for clinical use.

Ageberg et al. (2010) measured the inter-rater reliability of clinical assessment of single limb mini squats. They found the medio-lateral motion of the knee can be reliably assessed. However only two examiners were compared and both examiners discussed the scoring of the knee position before deciding whether there was agreement. The examiners did not assess the exercises in isolation. They state that the examiners received explicit guidelines and thorough training prior to study start, likely contributing to the achieved high reliability.

Blackburn et al. (2002) evaluated the inter-rater reliability of scores from two physiotherapists using the Modified Ashworth Scale to assess patient muscle tone during stroke rehabilitation. They found the inter-rater reliability of the physiotherapists to be poor.

Chmielewski et al. (2007) investigated the inter-rater reliability of two methods used for the evaluation of movement quality during rehabilitation. Three clinicians assessed twenty-five healthy subjects performing exercises. They found that agreement was better than chance but neither method used for clinical assessment produced high agreement. They conclude that the results indicate a need to develop more explicit criteria for rating movement deviation severity.

A common theme within the literature is that inter-rater agreement is often low and that there is a need for more objective criteria to support raters, including the use of instruments for testing.

3. EVALUATION METHODOLOGY

This section details the evaluation methodology and criteria the physiotherapists followed in order to assess the performance of the technology intended to enable technology-assisted stroke rehabilitation.

Four practising physiotherapists were asked to rate the accuracy of human joint position estimations recorded from a commercial depth sensor (Kinect v2 pose estimation algorithm) of a participant performing five stroke rehabilitation exercises. Several repetitions of each exercise were performed by a healthy participant. The physiotherapists used their expert opinion to rate the accuracy of the joint estimations, using the evaluation criteria in Table 1, and highlighted any clinical implications there may be in making an assessment. The physiotherapists viewed video and depth recordings of the exercises with the estimated joint positions overlaid, as shown in Figure 1.

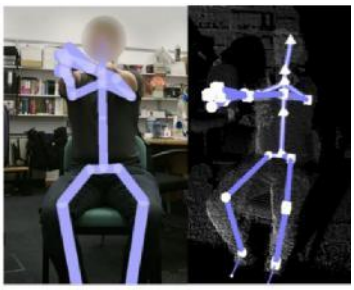

Figure 1. *The video and depth data available to the physiotherapists when performing an evaluation of the estimated joint positions.*

Table 1. *Physiotherapists used the following criteria for rating the accuracy of the estimated joint positions for each stroke rehabilitation exercise.*

Evaluation Criteria	
Acceptable tracking (AT)	The joint's estimated positions' result in an acceptable difference from the true position. The error in the position does not lead to misclassification in the assessment, e.g. a limb is showing no flexion when no flexion is occurring.
Moderately acceptable tracking (MT)	The joint's estimated positions' result in a moderately acceptable difference from the true position. The error in the position leads to a minor misclassification in the assessment, e.g. a limb is showing minor flexion when no flexion is occurring.
Unacceptable tracking (UT)	The joint's estimated positions' result in an unacceptable difference from the true position. This change in position leads to a significant misclassification in the assessment, e.g. a limb is showing severe flexion when no flexion is occurring.

4. RESULTS AND EVALUATION

Figure 2 shows the observations with the most divergence of opinion i.e. the observations with a standard deviation of 0.71 and above. The first observation shows that physiotherapist 1 believed the estimated joint position led to a significant misclassification in the assessment, whereas physiotherapists 2 and 3 believed the estimated joint position did not lead to a misclassification in the assessment.

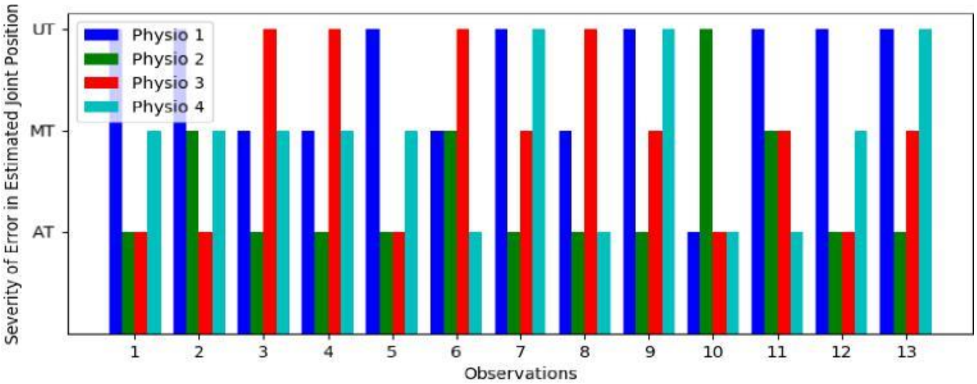

Figure 2. *Observations with the most divergence in opinion. See Table 1 for the definitions of AT, MT and UT.*

Figure 3 shows the observations with the most agreement in opinion. Of all the thirty observations only three were found to have agreement by all four physiotherapists and these observations were rated as unacceptable tracking.

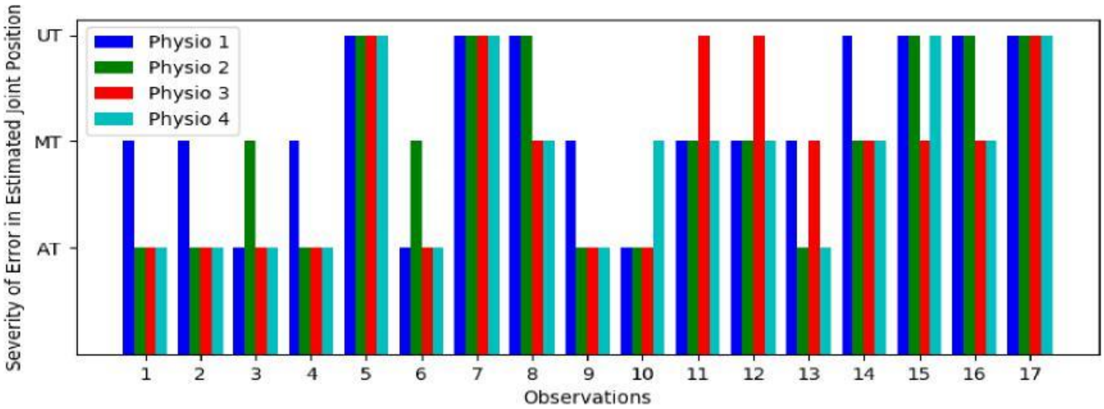

Figure 3. *Observations with the most agreement in opinion. See Table 1 for the definitions of AT, MT and UT.*

Krippendorff's alpha (2007) provides a statistical measure of inter-rater agreement. These observations have a Krippendorff alpha of 0.28, indicating a relatively low level of agreement thus supporting the findings by Barth and Blackburn. Table 2 shows the number of ratings each physiotherapist gave to each category. P1 tends to be much harsher, flagging more observations as showing 'unacceptable tracking' than the other physiotherapists.

Table 2. *The number of ratings for each category each physiotherapist has rated the estimated joint positions for all observations.*

	AT	**MT**	**UT**
P1	4	11	15
P2	15	8	7
P3	12	9	9
P4	11	12	7

It should be noted that only a subset of joints considered important for assessing the exercise were observed by the physiotherapists, for example limb joints. These results highlight the difficulty for clinicians to accurately assess the suitability of technology intended for clinical use. However, this was a small study. It remains inconclusive whether the raters' variability in assessment was due to the medium of visualising the data, limited training on the task and/or the criteria they followed.

To aid raters' in the clinical assessment of technology, we propose the incorporation of objective measures within the rater criteria to ensure a more structured and objective approach to evaluation. For example, when assessing whether joint position estimations, tracking a human skeleton, from a depth sensor is sufficiently acceptable for clinical use, the joint estimations from a more robust technology could be used as a ground truth, such as a motion capture studio, in order the measure the accuracy of the depth sensor. This would provide the assessors with error distance measures of estimated joints helping guide their final decision. Table 3 shows an example of an updated criteria, incorporating the objective measures, the raters could use to guide their assessment.

Table 3. *Example of an updated criteria from the original in Table 1, incorporating objective measures to guide the rater.*

Evaluation Criteria	
Acceptable tracking (AT)	The joint's estimated positions' have less than 2cm of error. The error in the position does not lead to misclassification in the assessment, e.g. a limb is showing no flexion when no flexion is occurring.
Moderately acceptable tracking (MT)	The joint's estimated positions' have between 2cm and 8cm of error. The error in the position leads to a minor misclassification in the assessment, e.g. a limb is showing minor flexion when no flexion is occurring.
Unacceptable tracking (UT)	The joint's estimated positions' have above 8cm of error. This change in position leads to a significant misclassification in the assessment, e.g. a limb is showing severe flexion when no flexion is occurring.

Furthermore, due to the literature indicating high inter-rater variability in expert clinical assessments, objective measures from technological tools could aid in the objective assessment of patient performance. For example, within stroke rehabilitation, tracking the patient's joint positions would provide measures such as arm flexion, by calculating the angle around the elbow joint, or calculating the range of motion. This approach could provide a fair assessment using calculated performance measures to determine the range of motion, severity of compensatory movements and stability in movements, etc.

5. CONCLUSIONS

We have evaluated the inter-rater reliability of clinicians rating the suitability of a new technology intended for clinical use. The results indicate a low level of inter-rater agreement suggesting that relying solely on the opinions of clinical experts for determining the clinical validity of new technology may be insufficient. It is still unclear what factors may have contributed to the inter-rater variability, such as the medium used for assessment, insufficient training on the new task and/or an inadequate grading criterion. However, we hypothesise that the introduction of technological tools that provide objective measures can be incorporated into the assessment criteria in order to guide clinicians' decision making, encourage an objective evaluation and improve inter-rater agreement.

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Vestibular rehabilitation comparing virtual reality therapy with traditional vestibular physical therapy

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[1–5]*http://www.med.navy.mil/sites/nhrc/Pages/default.aspx*

ABSTRACT

Patients diagnosed with vestibular dysfunction require vestibular physical therapy to mitigate gait and balance deficits. Physical therapists use a variety of traditional therapy techniques that target patient symptomology and novel virtual reality (VR) therapies. Although immersive virtual reality environments (iVREs) are becoming more common, little is known about the effectiveness of VR modalities in this population. This study compared 3 different treatment programs for military members with concussion. Group 1 performed traditional therapy, Group 2 performed VR-based therapy, and Group 3 performed a combination of traditional and VR therapies. The Activities-specific Balance Confidence scale, Dizziness Handicap Inventory, Functional Gait Assessment (FGA), and Sensory Organization Test were administered before (T1), during (T2), and after (T3) a series of 12 therapy sessions over 6 weeks. A significant difference was found at T2 for the FGA between Groups 1 and 2 (p=.001), with higher scores reported for Group 2. No other significant differences were observed between the groups. The difference in FGA scores may be due to the effect of treadmill walking or therapy engagement within the iVRE during therapy. Future research could include a broader population of patients with vestibular dysfunction to determine the effectiveness of iVREs on vestibular physical therapy.

1. INTRODUCTION

Concussion can lead to chronic symptoms involving a constellation of cognitive, emotional, and physical complications. Visual disturbances and vestibular complaints, such as postural imbalance, vertigo, headache, and dizziness, constitute the most common sequela of symptoms sustained from concussion in this population (Hoffer et al, 2004; Johnson et al, 2014). Many patients diagnosed with vestibular dysfunction are referred to physical therapy for treatment. Physical therapists utilize a variety of exercises to challenge patients physically and cognitively to assist in the recovery of visual, vestibular, and somatosensory function. In a traditional clinical setting, individualized exercise programs focus on gait training, desensitization of head and/or body motion, as well as improving gaze stabilization and postural control (Alsalaheen et al, 2010; Gottshall, 2011).

As new technologies emerge, clinicians are able to track patient outcomes more accurately and efficiently, allowing the constellation of deficiencies associated with concussion to be treated in novel ways. New research reveals virtual reality (VR) therapy to be an effective technique for improving balance and confidence in those affected by vestibular dysfunction (Thornton et al, 2005). Immersive VR technologies allow patients to practice challenging balance tasks simultaneously with cognitive tasks in an interactive environment, similar to that which they might encounter in real-world settings. Previous research suggests a benefit in training those with concussion using an immersive virtual reality environment (iVRE) (Gottshall and Sessoms, 2015). Little is known about the effectiveness of using VR modalities compared with conventional therapeutic methods to treat vestibular and balance dysfunction in subjects with concussion. The purpose of this study was to evaluate the effectiveness of vestibular physical therapy in an iVRE compared with traditional clinic-based vestibular physical therapy.

2. METHODS

Patients diagnosed with concussion and referred for vestibular physical therapy were recruited for this study. Those that provided informed consent to participate were assigned to 1 of 3 therapy groups—Group 1: patients performed a traditional clinic-based vestibular physical therapy program; Group 2: patients performed a vestibular physical therapy program using an iVRE; and Group 3: patients performed a vestibular physical therapy program consisting of a combination of alternating clinic- and VR-based treatment sessions. Therapy included 12 sessions across a 6-week time period, with 2 half-hour sessions each week.

2.1 Subject Population

Thirty patients participated in this study (age: 29.1±5.8 years; height: 178.2±9.9 cm; weight: 85.6±13.1 kg) with 10 subjects in each group; no significant differences were observed between group demographics. Subjects were between the ages of 18 and 55, had received a concussion within the past year and presented with chronic symptoms needing vestibular physical therapy, and were able to tolerate the physical aspects of treatment programs without walking assistance (i.e. walker or cane). Patients were excluded from participating if they had significant visual or hearing abnormalities, were pregnant, or had severe limits to mobility. Those with benign paroxysmal positional vertigo (BPPV) were also excluded from the study. Subjects were randomly assigned to one of the three therapy groups.

2.2 Immersive Virtual Reality Environment

The iVRE used in this study was a Computer Assisted Rehabilitation Environment (Motekforce Link, Amsterdam, The Netherlands), which consists of a 6 degree-of-freedom motion platform, a force-plate instrumented treadmill, and synchronized visual displays projected onto a 180-degree screen. Patients interacted with the iVRE using an optical motion capture system (Motion Analysis Corp, Santa Rosa, CA, USA).

2.3 Therapy Groups

Patients assigned to Groups 1 and 3 completed traditional clinic-based vestibular physical therapy and cognitive tasks prescribed by their therapist. Tasks included balance exercises with eyes open and eyes closed on varying surfaces and with varying limb stance, vestibulocular reflex, and adaptation exercises in sitting, standing, and walking. Cognitive tasks were added to the exercises, as appropriate for each patient, and included engaging in conversation during balance or adaptation tasks, memory recall, and performing simple math equations during exercises.

Patients assigned to Groups 2 and 3 performed a series of tasks in the iVRE, which challenged patients physically and cognitively, while engaging with static and dynamic visual displays synched with platform motion that moved with the terrain of the visual display. VR tasks included walking on level, hilly, and sloped paths while simultaneously performing tasks, such as answering math equations or hitting flying objects on the screen. In other tasks, they were asked to identify and shoot targets using a simulated rifle while walking, or to balance and steer a simulated boat through an open water obstacle course by shifting their weight laterally and sagitally (Gottshall and Sessoms, 2015). Levels of difficulty for the VR tasks were determined by the vestibular physical therapist, based on the patient's symptom levels for each day and their prior performance. Task difficulty was increased by modifying physical challenges, such as increased platform motion and treadmill speed, as well as cognitive challenges, such as stimulus frequency and equation difficulty.

2.4 Outcome Measures

Traditional clinical therapy assessments were administered prior to the start of therapy (T1), between sessions 6 and 7 (T2), and following session 12 after completing therapy (T3). These assessments included the following:

2.4.1 Activities-specific Balance Confidence (ABC) Scale.

The ABC scale is a 16-item, self-report questionnaire used to measure the psychological impact of balance confidence in performing daily tasks. Subjects were asked to score their ability to perform daily tasks on a scale of 0% (no confidence) to 100% (total confidence).

2.4.2 Dizziness Handicap Inventory (DHI).

The DHI measures self-perceived handicapping effects imposed by dizziness. It consists of 25 items classified into physical, functional, and emotional domains associated with dizziness. Answers are graded on a scale of 0 to 4, with total score ranges from 0 to 100—the latter signifying the highest degree of impairment.

2.4.3 Functional Gait Assessment (FGA).

The FGA is a set of 10 gait tasks with a standardized grading system, with scores based on the subject's ability to walk under different conditions (e.g. eyes closed, backward, changing speed). A total score of 30 is possible, with a score ≤25 demonstrating an increased risk of falls.

2.4.4 The Sensory Organization Test (SOT).

The SOT is a 6-condition balance test carried out using computerized dynamic posturography. The SOT identifies abnormalities in the 3 sensory systems that contribute to postural control: visual, vestibular, and somatosensory. Scores near 100 represent more postural stability and scores closer to 0 represent less stability.

3. RESULTS

Scores for each of the clinical vestibular tests were measured for central tendency across the 3 groups. Independent samples t-tests were conducted to identify significant differences between groups at the 3 study time points (Figure 1). The alpha level was set at 0.05.

Independent samples t-tests displayed significantly different variances (Levene's Test for Equality of Variances) among the groups and time points for FGA and SOT; however, the FGA at T2 was the only test to result in a significant difference in mean values between Groups 1 and 2 ($t(18)=^{-}4.160$, $p=.001$).

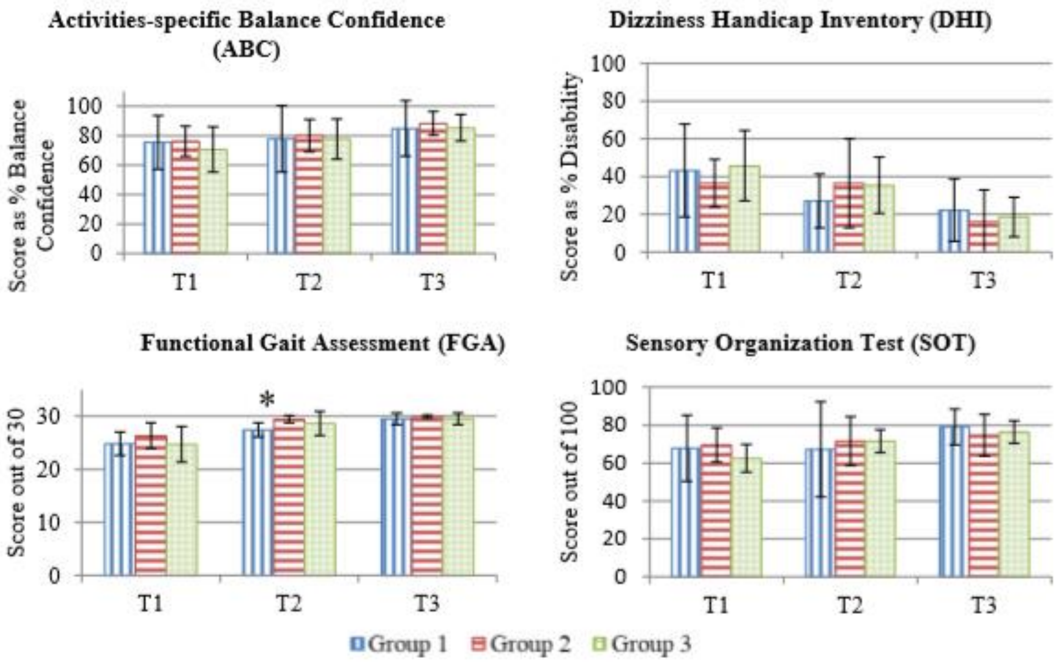

Figure 1. *Mean values of subjects in each group for clinical vestibular tests at 3 times points (T1, T2 and T3 over a 12-week period. Error bars represent standard deviations. "Significant difference in FGA at T2 between Group 1 and Group 2 (p=.001).*

4. CONCLUSIONS

The results of this study indicate that vestibular therapy conducted in the iVRE produces similar treatment outcomes to vestibular therapy conducted in the traditional clinical setting on 4 common clinical outcome measures. These results suggest that vestibular physical therapy treatment programs for concussed patients using iVREs can be an effective alternative to conventional, clinic-based vestibular therapy treatment programs.

The higher FGA score observed for Group 2 at T2 may be due to the treatment prescription. Group 2 received treadmill walking as part of the iVRE therapy program, while patients in Group 1 did not engage in regular treadmill walking during traditional therapy. Group 3, who received half of their therapy sessions within the iVRE, did not show significant differences between Groups 1 or 2. It is also possible that the multimodal engaging environments within the iVRE may have improved outcomes on the FGA.

Future research should explore the comparison of traditional and iVRE vestibular physical therapy programs in a broader population of patients with vestibular dysfunction, such as those diagnosed with vestibular migraine or Ménière's disease, to determine if the results seen in this study can be replicated. More specialized tasks to treat the specific needs of vestibular patients could also be explored using tailored VR applications that simulate scenarios patients have trouble with in their daily activities or job tasks.

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Disclaimer: I am an employee of the U.S. Government. This work was prepared as part of my official duties. Title 17, U.S.C. §105 provides that copyright protection under this title is not available for any work of the U.S. Government. Title 17, U.S.C. §101 defines a U.S. Government work as work prepared by a military service member or employee of the U.S. Government as part of that person's official duties.

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Development of colour vision test game for android devices

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ABSTRACT

In this article, a game is presented to support early recognition of colour vision problems. The basics of the game are largely drawn from the game called Candy Crush which is popular with many people, but the rules of the game are different. Also, a new game mode has been added to the basic idea where the colours have to be sorted regarding their saturation. One of the modes tests the player with different levels and different colour to see how the players can differentiate between the different shades of a colour. The other game type tests how properly the user perceives the transitions and if they can put the colours correctly in rows.

Keywords: Android, smartphone, colour vision, colour deficiency

1. INTRODUCTION

There are rods and cones in the retina of a healthy man. With the help of the cones the colours are distinguishable, and the rods are responsible for seeing in the darkness. There are three types of cones that respond to different wavelengths of light: Optical waves of different wavelengths of red, green, and blue stimulate the three different cones. Depending on the type of wavelength of the incoming light we can differentiate between the colours. Differentiating also depends on the lighting, the power of the light and the amount of the light. The human brain only receives information about the amount of light, not about the wavelength. The cones operate in bright light and the rods are activated in dusk with less light intensity continuously taking over the function of the cones by decreasing the power of the light. In the end the rods will work instead of the cones (Kremers et al., 2016).

Colour defect is when some colours are changed, and we cannot distinguish the colours at all. The latter is called colour blindness which is a rare variant of colour deficiency. Colour blind people cannot distinguish between the colours. They see the world in different shades of black and white. Colour deficiency occurs when one of the cones is missing or does not function properly. The incoming light causes the cone to be excited by different levels than normal (Valberg, A, 2005). The most common is the reduction of red and green colour perception. The perception of blue colour is less frequent, so the most common colour vision impairment is red-green colour deficiency. Blue-yellow visual impairment is also present, but in smaller numbers.

2. MATERIAL AND METHOD

Multiple software, applications, web site solutions have been developed for visual inspection. The authors would like to introduce some of them. Similarly, to their own application, these help to filter possible visual impairments, but they are usually tested differently in people's colour vision.

The on-screen visual inspection can be said to be not as accurate and reliable as a test by specialists because several factors may play a role in how the user can see the colours. Such factors may include: the type of monitor (panel, resolution, number of colours displayed, screen refresh rate, etc.) or the lighting of the environment during the test. How far the external light source is, how does it affect the screen and there is a risk of "cheating" because the user can see the screen from a different – not permitted – angle.

2.1. Farnsworth-Munsell 100 HueColor Vision Test

This test is a website-based vision test which is the most similar to their application and we will explain it in detail later. Farnsworth published this colour tone test in 1949 and has been used many times to test colour vision (Farnsworth-Munsell, 2018).

Figure 1. *Farnsworth-Munsell 100 HueColor Vision Test for colour vision CC BY-SA 3.0 and Munsell Colour System (source: https://commons.wikimedia.org/w/index.php?curid=1955750)*

Upon starting the test, the user will know exactly what to do next. Each row should line up the colours according to saturation. The application helps the user, because the first and the last squares cannot be moved, and they provide guidance on exactly which colour transitions should be put together.

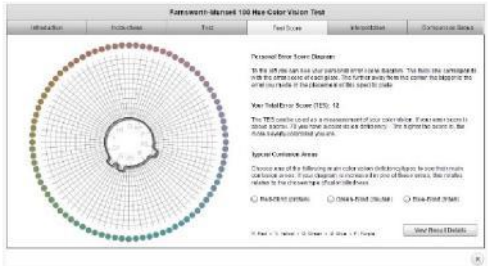

Figure 2. *Results of the Farnsworth-Munsell 100 HueColor Vision Test*

Starting the test itself, in Figure 1. the user interface can be seen. There, the user has to sort the squares in each line according to what the application tells the user. Once this is done by the user, the next page shows the results as can be seen in Figure 2. There are lines coming from the center. These indicate which colours cannot be seen well by the user. The more the line stands out, the greater is the confusion of the colour. They are marked in the middle with large letters (R = red, Y = yellow, G = green, B =blue, P = purple). Also, it also shows the colours at the edge with coloured circles.

This test is very similar to one of the games in the application where the user has to sort the colours regarding their saturation. In the introduced application, authors broke down the colour scales corresponding to the different colour deficiencies to different levels. So, the user can look at each area to see how many times a player has been mistaken for sorting colours. This will be described later.

2.2. Eye Test

Eye Test is an Android application with multiple vision testing tests, two of which test colour vision. According to Google surveys, this app has been downloaded over 1 million times (Eye Test Android App, 2018).

One certain colour vision test is called Color Blindness which is actually an Ishihara test (Ishihara test, 2018). In this test the user has to read a number from a circle built from dots. The dots have different colours or saturations than the actual number that you have to read. People with colour deficiencies have problems reading the numbers or they confuse them with other numbers.

2.3 Motivation

When designing the game and determining the rules, an existing game called Candy Crush (Candy Crush Android App, 2018) gave the inspiration. This game can be found both on computers and smartphones. The game was downloaded to Android devices by hundreds of millions (100-500 million to be more exact).

When choosing the topic, the goal of the authors was primarily to use a fun game to detect people's visual deficiencies during gameplay. With such a game, you can diagnose problems of colour vision as early as possible because children already have smartphones when they are young. In addition, one of the important expectations was simplicity: All age groups, especially children should easily handle and use the application. Of course, applications like this cannot serve as a full colour vision test. The results are just indicative. If required, it is very important to contact a specialist after the results.

2.4 Method

As mentioned before, the game is based on Candy Crush. Only the method of putting together the coloured elements has been implemented in the ColorCrush game. This was extended in a way that in contrast to Candy Crush, where only adjacent elements could be swapped, any element could be replaced with each other using a few simple rules. Additionally, even assembling the elements is simpler because only triplets have to be searched.

2.5 ColorCrush Application

The startup screen of the application has 5 buttons. The Game button allows the user to get to the level selection menu. In the Settings menu, the user can enter or change the name used in the game. By clicking on the Description button, the user will find a description of the game which is similar to a user manual. With the help of the About button, the user can view the version number and the name of the developer of the game in a popup window. By pressing Exit, the game closes and Android exits the application.

There are 7 levels available in the triplet search game. There are two 4-level courses available in the colour sequence game, 4 for each level of difficulty. Playable levels are marked with underlines. The name of the triplet search levels is the colour composition. On the first practice level, the 3 basic colours are red, green and blue (RGB). Other level names are colour schemes. Except the 15-colour level, the other levels have 5 shades of the said colour. The name of the colour order levels indicates which of the two colours must be placed in the line of the transition. On easy difficulty there are 8 colours and on hard difficulty there are 16 colours that should be placed in a row.

2.5.1 Find colour-triplets

At the start of the game, a window will appear on the screen, giving the player the maximum number of steps. If the player does not enter anything and just clicks OK, the default value is set to 50. This is shown in the left side of Figure 3. The game will not allow any more steps than this. After this the game will commence.

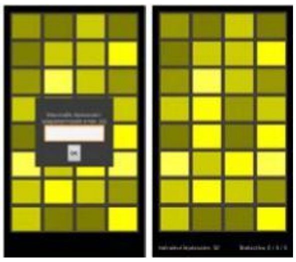

Figure 3. *Screenshots of "Find Color-triplets" game*

There are 32 color squares on the screen. The positions of these squares need to be changed by the player in order to align them vertically or horizontally. Three pieces of the same colour have to be aligned. Any two positions can be changed, not just the neighbouring ones. To swap the items, the player has to click on one and then click on the other one he wants to change. If three identical colours are next to each other, they will disappear, and their positions will be left empty. The empty square can also be replaced with another coloured square.

The game lasts as long as the user reaches the maximum number of steps or finds all possible triplets. The game will inform the player with a popup window.

There are two texts on the bottom of the screen: The remaining number of steps and the statistics. The former tells the user how many steps are left in the game. The statistics show 3 numbers. The first number is the good steps, the second is the "double good" steps and the third one counts the wrong steps. A good step happens when one of the two changed elements was placed in a position where the number of the same neighbouring colours is three. The "double good" move happens when two squares complete two triplets. The wrong move is when one square does not fulfill a triplet.

2.5.2 Colour orders

After starting the game, sixteen of thirty-two items will appear depending on whether the player has started an easy or hard level from the colour orders game.

The left side of Figure 4. shows the starting state of the game. In the top part, the user finds the squares that need to be sorted in the lower fields. The task can be seen over the lower area, or more precisely, which of the two colours should be placed in order.

From the top the user can select which item he wants to place in the line then he has to tap one of the lower boxes where he wants to move the previously selected box.

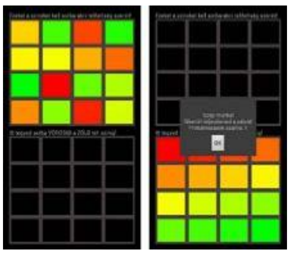

Figure 4. *Screenshots of "Color-orders" game*

3. TESTING

During development, the application was mainly tested on a 4.5" Jiayu G3T device. In addition, it has been tested on other devices including Sony Xperia X, Xiaomi Redmi 2 Pro, Samsung Galaxy S4, Nexus 5. There were no problems with the speed of the application as it ran smoothly on all devices.

At the start of development, a built-in emulator was used but in most cases, it was very slow. A new emulator was chosen, namely the BlueStacks (Judge, G, 2013) emulator. It was fast and there were no limitations that would have blocked testing. Shortly after using emulators, authors realized that testing on a physical device is more realistic, as there is a possibility for memory problems or other problems regarding graphical elements. Only the convenience of the emulators is the advantage. Testing was mainly done using a black box method. The developers did not take the internal structure of the application into account during testing. Only the behavior has been taken into account for some interactions and inputs. The application has been tested several times during development by other people. Based on the feedback, minor changes have been made to the user interface and to the logical structure of the application, so it should be well-developed for everyone.

4. CONCLUSIONS

An Android application has been designed and implemented that lets the user know what colour vision deficiency he has and tries to improve colour differentiation. Additionally, to the preparation of the application, the authors were able to get acquainted with the literary background of colour vision. To develop the application, Android Studio has been used as a development environment and Java was used as the programming language. The application can be played on smartphones and tablets that run Android operating system.

There are two types of game modes in the application. In the first, the position of coloured squares on the screen should be changed so that three identical colours are next to each other. This game lasts until the user finds all the triplets on the level or has reached the maximum number of possible steps. In the other game mode, there are two field groups on the screen. The colours of the fields at the top of the display should be placed in the lower field group. It is given on each track which two colours should be placed in this row.

The application can be developed further in many ways in the future. For example, it is possible to implement additional tests, to integrate help and to modernize the user interface. In addition, it is possible to optimize all display sized and resolutions. The results could also be stored in a database. An option would also be possible to send results via e-mail or access the results in some way without using the Android file manager.

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Qualitative research of an innovative virtual reality embodiment system: The Machine to Be Another

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ABSTRACT

The study of embodied technology has grown exponentially. The aim is to explore the user experience of a novel virtual reality embodiment system: the *Machine To Be Another (MTBA)*. The MTBA permits to see the users in the body of another person. A qualitative study using Focus Group and SWOT analysis was carried out with participants who had a previous experience with the MTBA. The current study is a part of a larger project and our first aim was to analyse the usability of this novel technology. Results show the main categories emerged and the analysis of the SWOT factors.

1. INTRODUCTION

In psychology and neuroscience, Virtual Reality (VR) is defined as an advanced form of human-computer interface that allows user to interact with and become immersed in a computer-generated environment in a naturalist way (Riva, Baños, Botella et al., 2016). VR can be defined also as an embodied technology due its ability to modify the feeling of presence and to induce body illusion (Kilteni, Groten, & Slater, 2012). The experience of our body results from the complex interplay of various perceptual streams involving vision, touch, proprioception, interoception, motor control, and vestibular sensations. All these aspects can be synthetized by the term "embodiment". Embodiment is the perception of own's body and it is based on three main aspects: the sense of self-location, the sense of agency, and the sense of body ownership (Kilteni et al, 2012). *Self-location* is a determinate volume in space where one feels to be located. Normally self-location and body-space coincide in the sense that one feels self-located inside the physical body. This location can break down when people have an out-of-body experience in which they perceive themselves outside of their physical body. The *sense of agency* refers to the sense of having a global motor control, including the subjective experience of action, control, intention, motor selection and the conscious experience of will. The *sense of body ownership* refers to one's self-attribution of the body, the conviction that the avatar is my own body (Kilteni Groten, & Slater, 2012). According to previous studies (e.g. Bailenson, 2013), is possible to alter body perceptions in healthy people in a controlled experimental setting, where the delivery of anomalous sensory stimuli is systematically manipulated. Following this point, VR has been successfully used to generate the illusion of ownership of different gender, race or even age, with changes in cognition and perception. For example, men that embodied a virtual female victim of violence from the first-person perspective, showed an improvement of their ability to recognize fearful female face (Seinfeld et al., 2018).

The current study is the first step in a larger research project focus to train compassion and self-compassion trough embodiment. The project was accepted by the ethical committee of Valencia University (nº *H1513592028862*). Compassion is understood as the feeling and understanding the pain of others, and then wanting to reduce that suffering. Self-compassion is the same willing directed to themselves. Data has shown that interventions based on compassion had an effect on stress, depression, burnout, and suicide (Kirbi et al, 2017). The development of technologies as Virtual Reality gives us innovative tools to develop new paradigms for compassion induction. The general research goal is to explore if embodied other person and see themselves in third person, could help the development of self-compassion. To reach that goal, we first focused our study on the effects and usability of an innovative VR embodiment system: the *Machine to Be Another.* The goal is to explore if this novel technology is efficacious enough to induce the sense of body illusion.

2. THE MACHINE TO BE ANOTHER

The *Machine to Be Another (MTBA)* is an embodiment system designed to address the relationship between identity and empathy. It is an advantageous technology for exchanging bodies (the real body with the avatar) which offers to the users an immersive experience of seeing themselves in the body of another person (Bertrand et al., 2018). The MTBA is a low budget body swapping system which, using the head-mounted display (the Oculus Rift in this case) participant sees the perspective of another person (performer) that mimics his/her movements. The performer's first-person perspective is captured by a camera controlled by user's head movements, revealing torso, legs, and arms of the performer's body. During the session with the MTBA, an audio system plays a narrative which explains the movements that the participants have to do. At the same time, the performer makes the same movements to induce the sense of body illusion to participants (Figure 1).

The research goals are focused on three main aspects:

1) the potential of the MTBA to induce the illusion of body ownership;
2) the psychological reactions of participants during the experience;
3) the features to enhance the sense of body illusion through the MTBA.

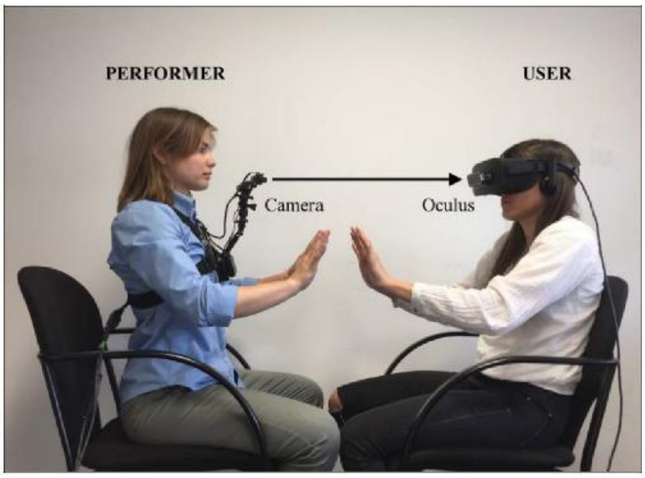

Figure 1. *The Machine to Be Another system.*

3. METHODOLOGY

4.1 Focus group

A qualitative study using focus-group methodology was conducted. It was considered that a group discussion would encourage participants to share experience and that, in group dynamics, is the group, rather than the constituent individuals, that is front and center (Nili, Tate, & Johnstone, 2017). Participants were categorized into two groups: (1) mental health professionals from the University of Valencia (Spain), (2) mental health professionals from the Jaume I University (Spain) who previously had an experience with the MTBA. Regarding the number, a total 10 participants who did the study with the MTBA were requested to participate. A final number of 9 participants attended to the focus groups: 5 participants of Jaume I University and 4 participants of the University of Valencia (1 person was unable to participate due to a schedule conflict). One researcher led each focus group and a second acted as an observer to document relevant contributions. The focus group structure was previously developed and consisted of open questions about their experience with the MTBA. This was carefully monitored by the focus-group moderator. Both sessions, of approximately 1 hour, were conducted in the Spanish language and were recorded and transcribed verbatim.

4.2 SWOT analysis

The SWOT analysis is an acronym that stands for strength, weakness, opportunities, and threats, and is commonly employed framework in the business world for analysing the factors that influence companies competitive position in the marketplace with an eye to the future. Generally, a SWOT analysis serves to uncover the optimal match between the internal strengths and weaknesses of a given entity and the environmental trends (opportunities and threats) that the entity must face in the marketplace (Rizzo & Kim, 2005). A strength can be viewed as a resource or capacity that allows an entity to achieve its defined goal. A weakness is a limitation, fault, or defect in the entity that impedes progress toward the defined goal. An opportunity pertains to internal or external forces in the entity's operating environment, such as a trend that increases demand for what the entity can provide or allows the entity to provide it more effectively A threat can be any unfavourable situation in the entity-s environment that impedes its strategy by presenting a barrier or constraint that limits achievement of goals (Rizzo & Kim, 2005). Following we presented the SWOT of the MTBA made after analysed the participants' experience.

4. RESULTS

Qualitative content analyses of the focus group were performed (Nili, Tate, & Johnstone, 2017). Texts were previously read to get a general sense of content. Subsequently, quotations of relevance to the study aim were identified and divided into meaning units (Table 1). Then, the SWOT factors of the MTBA were analysed (Table 2).

Table 1 *Examples of Representative Quotations of user experience with the MTBA.*

Themes	Quotations (representative)
Sense of Embodiment	
− Ownership	“at the beginning, I thought it was my body” “I realized that it wasn’t my body because I never wear swatch on the left wrist”
− Self-location	“Sometimes I believed I was at the other side” “I felt I was at the left side of the room instead of the right where I really was”
− Agency	“I’m moving...but is not my body” “I felt that another person was doing the movements, not me”
Psychological reaction	“the experience caused me anxiety” “it was a weird sensation, difficult to explain” “I felt uncomfortable because I knew that it wasn’t my body”
Suspension of belief	“I tried to convince myself that it wasn’t my body” “when I put attention on my arms, I realized that they weren’t mine” “all the time I tested the avatar to see if it was my body or not”
Visuo-motor/tactile synchronicity	“at a specific moment, I moved my finger to test if it was mine” “The avatar movements were a little delay” “My real movements were faster than the avatar”

Table 2 *Summary of a SWOT analysis of the MTBA.*

Strength	**Weakness**
• The sense of Embodiment induction (self- location, agency, and ownership) • Enhanced of ecological validity Out- • of-body experience • Stimulus control by the performer • Setting modification based on studies’ goal • Feeling learning • Realistic skin tone and body swap • First person perspective (1PP) • Low-cost system • A game factor to enhance motivation	• Proof-concept technology • Synchronicity (visuo-tactil and visuo-motor effects) • Constant engineering support • No free movements • Data extraction and analysis • Human resources required
Opportunity	**Threat**
• Emerging tech 1: concept’s improvement • Emerging tech 2: synchronicity’s improvement • Emerging tech 3: biofeedback and data analysis • Coworking • VR rehabilitation with a widespread approach to the public • Social acceptance	• Side effects (e.g. consciousness, cybersickness) • Suspension of belief • More advance embodied technology on the marketplace • Ethical challenges • The perception that technology is not good enough for rehabilitation

Results show that participants, during the experience, believed that they were inside another body and data presented shows that the MTBA has an impact on the three mains domains of the sense of embodiment: ownership (“*at the beginning, I thought it was my body*”), self-location, (“*sometimes I believed I was at the other side*”), and agency (“*I’m moving...but is not my body*”). The sense of embodiment caused psychological reactions to participants (“*the experience caused me anxiety*”) and the suspension of belief which participants believed and tried to convince themselves that what they saw and moved was not their own bodies (“*I tried to convince myself that it wasn’t my body*”). From data emerged also an important factor to inducing body illusion: the visuo-motor/tactil synchronicity (“*at a specific moment, I moved my finger to test if it was mine*”). According to SWOT data, the main results are that the MTBA has a high level of realism in terms of skin texture and body swap that permit the sense of body ownership illusion, but it falls in term of synchronicity which negatively affects the illusion. Developer should be improve its concept and data analysis.

5. CONCLUSIONS

The aim of this study was to explore if the novel technology of VR embodied system, the *MTBA*, is efficacious enough to induce the sense of body illusion and what could be its improvement. Results showed that the VR system is a good candidate for inducing embodiment. Important factor from the results is that participants had several emotional reactions as anxiety, weird sensation and some of them felt uncomfortable being in another body. This data should be taken into account for following studies. We also assisted to the phenomenon of suspension of belief which participants believed or tried to convince themselves that, what they saw and moved, was not their own bodies. This could happen because the MTBA has a little delay in the visuo-tactil synchronicity and it caused confusion to participants. Cause of that, participants could not understand if the body is their own or not. According to Slater (2013), the full body ownership illusion can modulate the way touch is perceived. Sometimes, asynchronous visuo-tactil cues can be consciously perceived as correct, especially when there is first-person perspective and realistic virtual body, as happen with the MTBA. To increase the visuo-tactil synchronicity, we decided to change some movements and introduce more tactile movements (e.g. "caress your leg or arm" instead of simply "watch your hands"). Moreover, a strength point of the MTBA is the first-person perspective and its level of realism in terms of skin texture and clothes that influence the strength of the full body ownership illusion. To enhance this point and thanks to participants' feedback, we suggested the performer (the virtual body) do not wear tools such as bracelets, rings or swatch that can interrupt the body illusion.

The current qualitative analysis gave us the opportunity to enhance the research protocol on compassion and to reach a higher sense of embodiment which is important for the goal study.

To sum, the potentialities of the MTBA as an embodied technology makes possible the study of behavioural, cognitive and emotional aspects that were hard to realize so far. And by designing meaningful embodied activities, VR can enhance therapy and promote significant changes. According to our qualitative work, we underline the importance to make a previous study of user experience especially when new concept of technology is used. The future challenge of the virtual reality embodied system could be a deeply study of the psychological aspects and personal feeling of participants during the full body illusion experience.

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The effect of visual feedback on performance of the star excursion balance test

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ABSTRACT

The aim of this study was to explore the effect of real-time visual feedback provided by a video camera on performance of the star excursion balance test (SEBT) in healthy subjects. We compared the performance of the SEBT using the maximum reach distance (MRD) in 20 healthy participants (10 male and 10 female, 26.8 ± 3.7 years) under two conditions: without feedback and whilst they viewed their movements in real time on a screen in front of them via a video camera. The results showed that real-time visual feedback had a significant effect on MRD of the SEBT in the posterolateral direction ($P < 0.001$). There was a non-significant increase in MRD in the anterior and posteromedial directions. This indicates that real-time visual feedback appears to be an effective means for improving the performance of the SEBT in the posterolateral direction, and may be a promising tool for clinical rehabilitation and athlete training to enhance dynamic postural control.

1. INTRODUCTION

The star excursion balance test (SEBT) is an important clinical functional performance test requiring adequate range of motion, muscle strength, and proprioceptive and neuromuscular adjustments to keep balance (Hyong and Kim 2014). It is being used to identify postural and balance control deficiencies related to lower-limb pathology, detect improvements in balance rehabilitation, predict lower-limb injury, and train both patients and healthy people (Hertel et al. 2006). Its reliability and validity as a convenient and inexpensive clinical approach for dynamic postural control have been evaluated in clinical and research settings (Gribble et al. 2012). However, the performance of the SEBT can be influenced by complex physiological systems in addition to the musculoskeletal system, such as vision, somatosensory and vestibular systems, which provide information on body sway and adjustments for corrective anticipatory postural behaviours (Peterka 2002). Vision plays an important role in postural and balance control as it provides unmatched, accurate and sophisticated information at the right time and a location that cannot be matched by other sensory modalities (Gribble et al. 2013). Visual feedback is a method using optical illusion to adjust and improve the motor strategy and movement (Nojima et al. 2012), which is originally used as mirror therapy to rehabilitate paralysed limbs using the reflection of the movement of the non-paralysed limb (Jeon and Choi 2015). Visual feedback enhances the training effect by compensating for the loss of somatosensory function after injury and enhances motor process in brain; thus it facilitates postural control and the effectiveness of the treatment (Ko et al. 2015).

Real-time visual feedback provides immediate and continuous feedback that can be used to correct movements during a motor task. It can be used to improve dynamic balance control and avoid falls and mistakes by influencing force production, accuracy and balance control (Howland 2016; Walker et al. 2016). The combination of the SEBT and real-time visual feedback may have a beneficial effect on dynamic postural control. However, to the authors' knowledge, previous studies on the effect of visual feedback have mostly used stance, walking and upper-limb functional tasks (Nojima et al. 2012; Hoff et al. 2015; Kelly et al. 2016), and there is no literature evaluating the effect of real-time visual feedback provided by a video camera on the SEBT. Exploring the use of video camera as a means of providing visual feedback on the SEBT can provide a reference for clinical training and effective interventions for people with dynamic postural control problems. Therefore, the aim of the study was to quantify the performance of the SEBT with and without visual feedback. If the results show significant improvements in the performance of the SEBT with visual feedback, the tool could be applied to clinical rehabilitation and athlete training to enhance the use of the SEBT for training dynamic postural control.

2. METHODOLOGY

2.1 Participants

A convenience sample of 20 healthy participants (10 male and 10 female) was recruited from Cardiff University to perform the SEBT under two conditions after providing written informed consent. Ethical approval was granted by the School of Healthcare Sciences Research Ethics Committee. The inclusion criteria were aged between 18 and 60 years, no history of neuromuscular diseases, and normal or corrected-to-normal vision. The exclusion criteria were musculoskeletal injury or other condition that may affect posture or balance control.

2.2 Procedure

After providing consent, participants were asked to perform a 5-min warm-up on a bicycle ergometer. After completing the warm-up, they were instructed to practice three SEBT trials in each direction to familiarise themselves with the procedure and to reduce the learning effect. The dominant limb was determined by asking the participants which leg they preferred to kick a ball with. This was used as the stance leg for all subsequent SEBT trials. To perform the SEBT, participants were instructed to put their arms on their waist and to reach the non-dominant leg as far as possible along the anterior, posterolateral, and posteromedial direction lines indicated by red tape on the floor, while keeping the dominant foot on the floor (see Figure 1). The posterolateral direction was to the side of the leg performing the task (i.e. reaching backwards and right if the right leg was performing the task), and the posteromedial direction was to the side of the stance leg (i.e. reaching backwards and left if the right leg was performing the task). The process of the SEBT was in the sequence of anterior, posterolateral, and then posteromedial. This order was designed such that the degree of difficulty gradually increased (i.e., the task in anterior direction is easier than that in the posterolateral and posteromedial directions, and posterolateral is easier than posteromedial) (Gribble et al. 2012). This sequence was chosen because it replicates the way the SEBT is performed in clinic and thus increases the external validity of the results (Johansson and Karlsson 2016). The interval between subsequent trials was at least 1 minute.

Participants performed the SEBT without visual feedback. In this condition they could look at their feet to follow the direction lines indicated on the floor (Figure 1. B, C, D). Then they were given a 2-min rest prior to performing the SEBT with visual feedback. In the visual feedback condition, they were able to view their lower-limb movements in real time on a screen located in front of them (Figure 1. E, F, G). In both conditions, participants were instructed to reach the maximum excursion and then touch the tape lightly with the foot so as not to aid balance, before returning to their initial upright posture. The point at which the participant touched the tape was considered as the maximum reach distance (MRD). MRD was recorded manually using a measuring tape, and all data were recorded to the nearest centimetre. MRD requires a combination of postural and balance control, related muscle strength, and range of motion of the stance limb (Herel et al. 2006). Therefore, it is associated with dynamic postural control of the stance limb, and thus was considered as the primary outcome of this study.

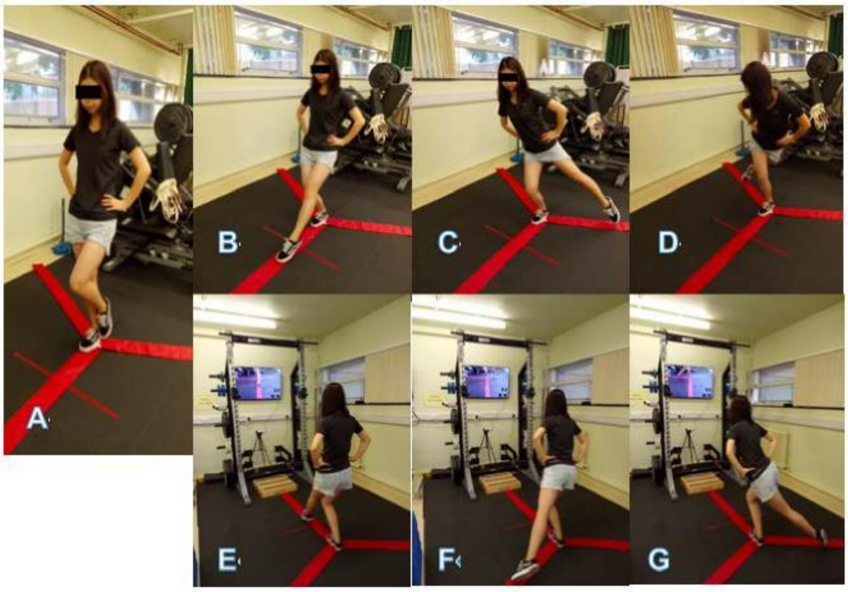

Figure 1. *Setup of the SEBT and a participant performing the test. A: upright posture; B: anterior without visual feedback; C: posterolateral without visual feedback; D: posteromedial without visual feedback; E: anterior with visual feedback; F: posterolateral with visual feedback; and G: posteromedial with visual feedback.*

2.3 Data Analysis

Data were analysed using Statistical Package for the Social Sciences software version (SPSS, version 23, IBM Corporation). Demographic information (age, gender, height and weight) was quantified using descriptive statistics to evaluate the heterogeneity of the sample and inform the generalisability of the results. The average MRD in each direction was calculated for each condition, and used for statistical analysis. According to the Shapiro-Wilk Test ($P > 0.05$), MRD was normally distributed for each of the three directions in each of the two conditions, and a repeated-measures ANOVA was therefore used to detect any effects of independent variables. Post-hoc comparisons were performed using paired t-tests with Bonferroni correction for multiple comparisons to explore significant main effects. Significance was defined as a probability level of $P \leq 0.05$.

3. RESULTS

Twenty healthy participants (age: 26.8 ± 3.7 years; mass: 70.4 ± 19.0 kg; height: 170.2 ± 9.8 cm; gender: 10 male and 10 female) took part in the study. Fifteen participants used the left leg as their standing leg, and five participants used the right leg.

In the posterolateral direction MRD with visual feedback was significantly larger ($F = 34.969$, $P < 0.001$) than that without visual feedback. There was no significant difference in MRD between the two feedback conditions in the anterior and posteromedial directions ($F = 0.412$ and 0.439, $P = 0.528$ and 0.515, respectively) (Figure 2).

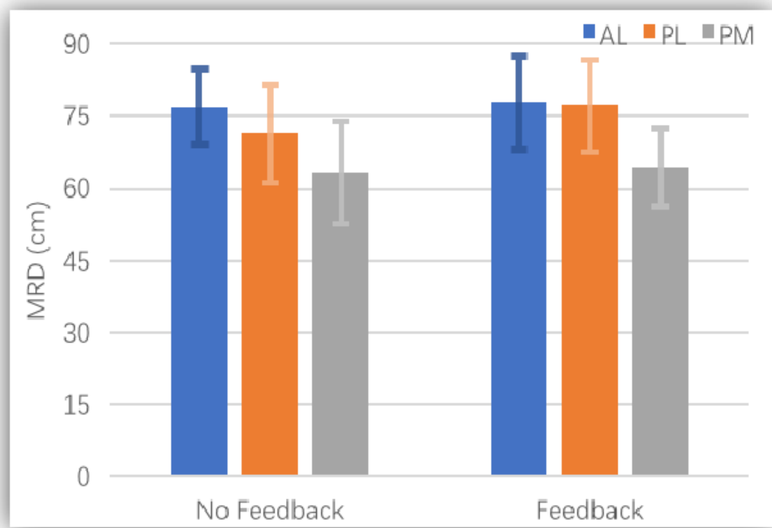

Figure 2. *Average maximum reach distance (MRD) in each of the three directions under two conditions. AL= MRD in the anterior direction, PL= MRD in the posterolateral direction, PM= MRD in the posteromedial direction.*

4. DISCUSSION AND CONCLUSIONS

Real-time visual feedback significantly improved the performance of the SEBT in the posterolateral direction, but not the anterior or posteromedial directions. The findings of this study are in line with previous research (Weon et al. 2011), which reported that real-time visual feedback provided by a video camera improved the movement of the upper limb by enhancing the activation of the related muscles. Real-time visual feedback encourages people to pay more attention to the execution of the task, and enables physical self-control through continuous visual information (Weon et al. 2011). The current study demonstrated a significant influence of visual feedback on the performance of the SEBT in the posterolateral direction. This has potential benefits for postural and balance control for healthy people (Gribble et al. 2013). This was evident by a positive effect of visual feedback on MRD in all directions, although it was not significant in the anterior and posteromedial directions. In the anterior direction, participants had almost the same view in both visual feedback conditions, and this may have resulted in the lack of any significant effect. The greater difficulty of the task in the posteromedial direction might have precluded any effects of the visual feedback (Hertel et al. 2006). The lack of significant effects in the anterior and posteromedial directions might also be due to the small sample size and the fact that all participants were physiotherapists who were familiar with the SEBT. Therefore, future work should increase the sample size and recruit a more diverse. The learning effect in this study was minimised by the performance of practice trials before the experiment.

The current study is, to our knowledge, the first study to explore the effect of visual feedback provided by a video camera on performance of the SEBT. The results can inform future clinical research of using real-time visual feedback combined with the SEBT to improve posture and balance control. Further work should consider whether the addition of real-time visual feedback to the SEBT can help identify and treat patients with lower-extremity injuries and other neuromuscular diseases, and thus improve rehabilitation. People with balance problems may have lower MRD than healthy people, and perhaps greater difference in MRD of the left and right than healthy people, and the SEBT performed with real-time visual feedback may be useful for identifying deficiency at an early stage. As for treatment, performing the SEBT with visual feedback may reduce the risk of falls and help patients correct and enhance the postural control behaviours. By comparing movements of the left and right legs on the screen in front of them, patients may notice the difference and weakness of the affected leg, which might trigger re-learning and implementation of a compensation strategy to improve balance control.

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The role of social interactions in a multiplayer context for rehabilitation games

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ABSTRACT

This paper presents an investigation into the effects of creating multiplayer rehabilitation applications, undertaken as part of a six-month internship with Motek Medical. Two approaches were taken; firstly, taking an existing rehabilitation game and integrating multiplayer mechanics, secondly, designing a bespoke cooperative game. Twenty-two participants took part in a pilot study and the results suggest that designing and developing with social gameplay in mind from the start leads to better perceived team communication than in an adaptation of an existing product. The results highlight one application being perceived as a more social experience, while the other was perceived as having clearer goals.

1. INTRODUCTION

Game-based rehabilitation "has the potential to provide patients with fun and motivating exercise tools" (Lange et al. 2016), getting patients engaged in the game to distract from the therapy process. The application of games in therapy is an established area of research, however as the quality of rehabilitation games increases more focus has been placed on the impact of social gaming within this context (Colman, 2014).

Implementing multiplayer or social elements to the rehabilitation process has a multitude of known benefits. The type of benefit varies dependent on the level of familiarity between patients and the game's genre. Gorsic et al. (2017) found a positive correlation between the degree of competitiveness in a game and an increase in exercise intensity. Meanwhile, Ganesh et al. (2014) suggest that patients benefit more from rehabilitation when playing with a peer (i.e. friends or family) rather than an expert or therapist. This has interesting design implications, particularly for competitive games, with regards to balancing a player's physical ability with gameplay mechanics to ensure a fair experience.

Additionally, the game's genre can impact a participant's enjoyment of and attention to the rehabilitation, as demonstrated by Novak et al. (2014). This latter study showed that when playing a selection of competitive and cooperative titles, results were frequently linked to a patient's personal game preference. Thus, when developing multiplayer games, an awareness of the need for both participants to have a mutual interest in the game genre or theme is beneficial.

2. PRELIMINARY FRAMEWORK OF ACCESSIBILITY BARRIERS IN DIFFERENT GAMEPLAY CONTEXTS

Additional to general game preferences of individual patients, it is also important to consider different accessibility concerns such as those outlined in the Game Accessibility Guidelines (2016). These accessibility concerns may differ depending on the gameplay context in question. A framework of gameplay contexts and accessibility barriers (the AC-BAR Framework, Figure 1) was created to aid the process of design and development of rehabilitation games. The gameplay context is representative of why an individual is playing the game; e.g. for social gain, as rehabilitation, or as a means of education. Each context has its own set of properties which must be met for a game to succeed in that context.

The accessibility barriers are made up of cognitive and physical, and single and multiplayer considerations, broken down into factors that can negatively affect the game experience. Some examples of barriers include the amount of physical effort required or the visuals of interactive elements. A rehabilitation context, for example, needs to appropriately gauge the physical effort required (i.e. if the effort required leads to physical exhaustion beyond that which is intended by design).

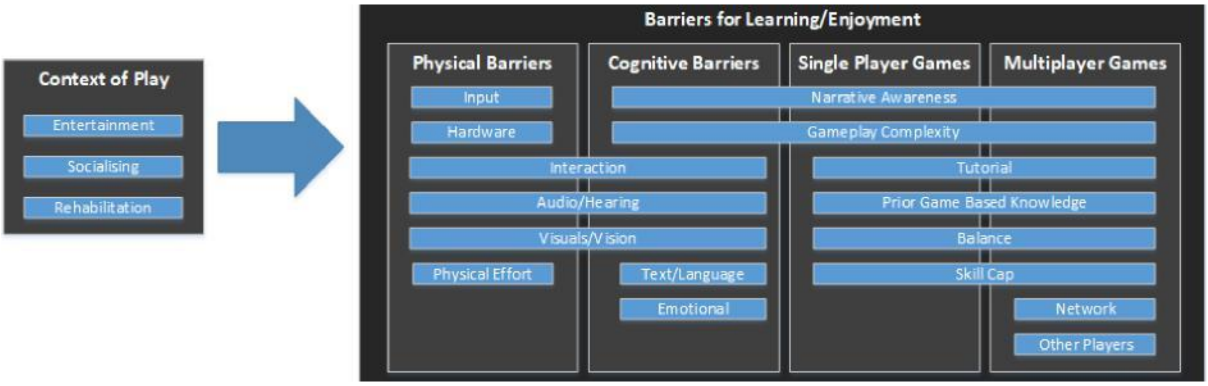

Figure 1: *The AC-BAR Framework.*

3. PROJECT OUTLINE & OBJECTIVES

3.1 Project Outline

Augmented performance feedback is an integral part of Motek Medical and Hocoma's (an affiliate company from Motek Medical) products and is used to motivate and engage patients during their rehabilitation exercises. Augmented performance feedback adds information from an external source to the intrinsic feedback in one of two ways: knowledge of results or knowledge of performance (Lauber & Keller, 2012). The exercises provide functional tasks in controlled environments using specifically designed games. The Armeo®Senso by Hocoma is a self-directed arm therapy device and part of the modular Armeo Therapy Concept, which can be used with multiple devices in one room. This is an ideal product to explore the feasibility of multiplayer games in a rehabilitation setting.

3.2 Objectives

The key objectives of the project are: (1) Design and create a multiplayer game for the ArmeoSenso by Hocoma and (2) adapt an existing Hocoma application for Multiplayer use. The games must feature social and fair gameplay, be functional on a range of products and for a range of patient functionality/treatment goals. The games must be competitive or collaborative in design.

4. USING THE AC-BAR FRAMEWORK TO MODIFY AND CREATE REHABILITATION APPLICATIONS

Figure 2: *Screenshots from Pirates (Left) and Road to Utopia (Right)*

Pirates (Figure 2, left) is an existing application currently used for rehabilitation by Hocoma and is one of the most popular titles with their patients. It was originally a single player experience for the Armeo®Senso in which players aimed and shot at the pirates that appeared on screen. Text for score and ammo count had to be included which was kept bold and contrasting to coincide with the AC-BAR Framework. Information on each player's health, score, and ammo count are synced across the server, allowing all players to see the information about themselves and their allies.

Road to Utopia (Figure 2, right) is a bespoke product designed using the AC-BAR Framework via intentional considerations, such as not including on-screen text or significant narrative, thus avoiding aspects of the narrative awareness and visual barriers. The 2D visuals are bold with a clear contrast between foreground and background elements providing visual clarity. This design also assists those with spatial perception cognitive issues, which hinders peoples' "ability to perceive our surroundings with shapes, sizes, distances, etc." (Cognifit, 2018), by removing a dimension. The visual style allows the interactive elements to be clearly identifiable, avoiding some of the visual barriers outlined within the AC-BAR Framework.

5. STUDY OVERVIEW

5.1 Methodology

Each participant played the two applications for a total of ten minutes. Twenty-two participants were gathered using convenience sampling, all of which were Motek employees. After completing each session, participants were asked to fill out a digital questionnaire based on the Game Accessibility Guidelines (2016), the Game Experience Questionnaire (IJsselsteijn et al, 2013) and the Game-Based Evaluation Methods (Oprin, et al, 2015) focusing on different aspects of the AC-BAR Framework.

5.2 Results

A t-test was conducted to determine if a difference existed in the *"Goal Clarity"* data. A marginal significant difference was found ($t(42) = 1.94$, $p = 0.06$), with *Pirates* (mean = 4.09) higher than *Road to Utopia* (mean = 3.41). However, the *"Playing Together Contributing to the End Result"* data showed *Road to Utopia* (mean = 4.23) was significantly greater ($t(42) = -2.03$, $p<0.05$) than *Pirates* (mean = 3.50).

There were no other significant differences for the twenty-one other variables of the questionnaire, confirming that both applications were equally perceived; fun to play, not physically exhausting and able to hold participant attention. Importantly, the mean values for *"I was able to hold my attention during the game"* and "*The game was fun to play"* in the context of *Road to Utopia* both exceeded 4 (on the five-point Likert scale), highlighting its positive reception from the participants. The highest mean value recorded however for *Road to Utopia* with 4.41 in the variable *"The game did not feel like therapy"* compared to the 4.36 of *Pirates*. Both of these high means demonstrate the potential for games such as these being used for rehabilitation without being perceived simply as therapy tools by participants.

A Spearman's correlation was conducted and a significant positive relationship was found ($r(51) = 0.933$, $p<0.01$) between *"Holding Attention"* and *"Having Fun Together"* within *Road to Utopia*. Out of all the correlations identified, this was the most significant with the highest value. For *Pirates* the highest significant positive relationship found was ($r(51) = 0.7$, $p<0.01$) between *"The Game was Simple to Understand"* and *"Goal Clarity"*. This makes logical sense as there is a fair amount of cognitive overlap with the goals of the game and understanding the game overall.

6. DISCUSSION

6.1 Benefits of Design vs Adaption in the Context of "Playing Together Contributing to the End Result"

The data shown reinforces the idea that an experience principally designed to be social yields better perceived benefits within participants than an existing application adapted to include multiplayer features. Both games scored highly in the Entertainment context, however in the context of multiplayer applications, *Road to Utopia* was voted significantly higher as based on the t-test results. This can be in part attributed to the intentional cooperative design.

6.2 Goal Clarity and Application Simplicity

Pirates scored significantly higher for *"Goal Clarity"*; the application fits within the established game genre of Arcade Shooter where participants must identify targets, move their cursor and shoot. *Road to Utopia* however introduced a unique collaborative movement system, with players guiding a herd of minions. Players may find this movement system and game goal less clear as it fits less readily fit within an established game genre. The conclusion from this finding is that more work needs to be done to improve the goal clarity for *Road to Utopia*, perhaps through adjustments to the control scheme.

6.3 Limitations

This study has some limitations that should be noted. The use of convenience sampling will impact the results and the study should now be extended to include patients to obtain more valid data, if the applications are deemed suitable for this purpose. Additionally, the access to the Armeo®Senso hand module was limited with only one device shared between participants, thus limiting synchronous social play using this device.

7. CONCLUSIONS

7.1 Concept Evaluation

It is too early to suggest definite benefits of using multiplayer games for rehabilitation however the pilot study is supportive of the concept, with both applications evaluated as enjoyable. Further adaptations to the applications would be needed before medical use but as a first step to explore the feasibility, this initial study has been successful in identifying an avenue for future research.

7.2 Directions for Future Work

There are three significant areas to explore further. Firstly, continuing to design bespoke multiplayer applications; the social experience is stronger with a cooperative game than two participants experiencing a game simultaneously but non-cooperatively. Secondly, exploring the differing benefits of patients playing cooperative or competitive titles; there may be a subset of patients who are more intrinsically motivated by competition and put more effort into rehabilitation. Lastly, the impact of online, rather than local, multiplayer within rehabilitation; the pilot study was carried out with co-located participants and it would be interesting to examine how communication and engagement is affected by changing this to involve non-co-located participants.

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Creating personae for personalising a visual programming tool for children with autism spectrum condition: A proposed methodology

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ABSTRACT

Designing and developing accessible educative and entertaining technologies for children with Autism Spectrum Condition is no easy task due to their diverse needs and capabilities. In theory, accessibility can be achieved by personalising technologies based on the unique capabilities and needs of each individual. However, that requires knowledge of the capabilities and needs of each individual. A potential solution to this challenge is to use Personae; a persona provides a detailed description of a user in addition to the user's capabilities, needs, challenges and goals. In this paper, we propose a method of creating personae for children with Autism Spectrum Condition to be used for personalising a visual programming tool. This method will take advantage of existing personae by extending them to fit the needs of our current context.

1. INTRODUCTION

Autism Spectrum Condition (ASC) is a developmental disorder that is characterised by impairments in social communication, restrictive or repetitive behaviours, and peculiar interests. It affects an estimated 1.1 percent of the UK population (Autism facts and history, 2018).

Visual programming tools such as Scratch (Maloney et al., 2010) and PocketCode (Slany, 2014) have been created specifically for children to learn programming and create digital content such as games and stories. They provide inbuilt media elements (backgrounds, sprites and sounds), support the creation of new media elements, and allow definition of instructions using scripts made up of visual blocks. However, such tools are still not completely accessible to children on the autistic spectrum. Our previous work (Zubair et al., 2018) evaluated the accessibility of Scratch when used by children with cognitive impairments, five out of the seven participants in the study had ASC. The study revealed some of the constraints that may stand in the way of children with ASC when using Scratch and other visual programming tools. The constraints were divided into two issues: those related to the user interface, and cognition related issues. User interface related issues are those that are directly caused by the interface design of the software and how it is interacted with, they include difficulties associated with: differentiating buttons and their uses, differentiating scripting blocks within the same category, recognising links to media groups and block categories, selecting and dragging media and blocks, and switching between different panes. Cognition related issues on the other hand are related to the cognitive processes required by users to effectively use the software, they led to difficulties in: defining instructions (scripts), structuring and sequencing actions and events within a project, and staying on track to complete a project.

Addressing user interface related issues, in theory, can be done by following user interface design guidelines for designing software for individuals with ASC such as those proposed by Britto and Pizzolato (2016). However, when tackling cognition related issues, it is important to avoid coming up with a one size fits all solution. Eliminating all the cognition related difficulties may create software that is accessible to all users but no longer cognitively challenging for some users. Therefore, it is essential to have software that can be personalised based on the capabilities and requirements of each individual user. In doing so, the software will be cognitively accessible by providing the right kind of support to the user in areas or tasks in which they lack strength. This approach will ensure that each user is able of making productive use of the tool, and using their problem solving and creativity skills, without becoming frustrated and uninterested. However, the success of this approach depends on being able to find an appropriate method of understanding the unique needs and capabilities of the target users.

Personae can be used to provide the user descriptions required for software personalisation. Personae were introduced by Cooper (2004) as tools for providing detailed and specific descriptions of users and their goals. They

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provide rich qualitative descriptions that breathe life into target users and promote empathy among designers. Users represented by personae are imaginary not real people, they are "hypothetical archetypes of actual users", or representations of real users (Cooper, 2004). However, being imaginary does not mean they are completely made up, personae are developed through a well-defined methodical investigation of users. Cooper et al. (2007) described a method of constructing personae, the method has seven stages that begin after the completion of data collection through observations, interviews and/or focus groups. The first step is 'identifying behavioural variables', which is done by recording distinct patterns of behaviours from the data. Subjects whose data was collected are then mapped to the behaviours they exhibit from the set of recorded behavioural variables. Subjects with seven to eight links to common behaviours are then grouped together, each group forms the basis of a persona. Details are then generated from the collected data for each pattern of behaviour that has been identified. Personae are then verified to make sure they are complete and not repetitive i.e. checked to ensure they represent all potential target users, no two personae are very similar. Existing details are then expanded to include rich descriptions from the data to make the persona more descriptive and real. Finally, types that determine the priority or order of use are assigned to the finalised personae.

Personae can be reused when designing new versions of the technology they were created for, they can also be reused for designing similar technologies, or technologies for the same target group (Adlin & Pruitt, 2010). However, in some situations, existing personae may need to be modified to be suitable for a new context of use. The new context might be designing a new technology, even if the target users are the same (Adlin & Pruitt, 2010).

The aim of this paper is to propose a method of creating personae for children with autism spectrum condition to be used for personalising a visual programming tool. This method will take advantage of existing personae by extending them to fit the needs of our current context. The section that follows briefly discusses works on the use and creation of personae for children with autism. It is followed by a section that presents our methodology for personae creation. Further work and conclusions are presented in the penultimate and final sections respectively.

2. RELATED WORK

Very few reports on the use of personae for designing technology for children with ASC were found during literature review, furthermore not all the reports found outlined the methodology followed in creating their persona(e). Al-Wabil et al. (2012) and McCrickard et al. (2013) reported the use of personae for designing an Arabic auditory system for children and to inform designers of assistive technologies respectively. However, both reports lacked detail in describing the methodology used to create the personae. Al-Wabil et al. (2012) only mentioned that the developed personae are data driven and that they were validated by domain experts. However, the steps in developing and validating the personae were not revealed. McCrickard et al. (2013) reported the creation and approval of two personae through a collaboration of Human Computer Interaction (HCI) specialists and psychologists familiar with autism but did not disclose much of the methodology used. One of the two personae described concerns a six-year-old boy named Greg, and the other described a seven-year-old girl named Isabela. Both Greg and Isabela were described as having high functioning autism spectrum condition, and their personae had a list of habits and activities typical of children with high functioning autism with their unique backgrounds.

Leal et al. (2016) reported the creation of a persona for the design of applications for children with ASC using a method based on that described by Cooper et al. (2007). Qualitative data were gathered through review of literature via search engines (e.g. Scopus, Web of Science, and PubMed), as well as books on autism spectrum condition. Additional qualitative data were collected from caretakers and professionals with experience of working with children with ASC, who provided insight into the daily activities performed by the target users. Relevant characteristics and objectives were then extracted from the data and narrated to make up the Persona. This enabled Leal et al. (2016) to provide a rich description of the user, thereby creating empathy and emphasizing what is at stake to the designer. Finally, the persona was verified by obtaining opinions from five experts regarding the correctness of the statements that make up the persona, and the persona itself. These opinions were collected using a five level Likert scale questionnaire. However, Leal et al. (2016) realised that although the questionnaire allowed respondents to give quantitative opinions on the persona using the Likert scale, there was no means for the respondents to provide any further feedback.

3. PROPOSED METHOD

The method proposed in this paper is based on the method for constructing personae described by Cooper et al. (2007), with modifications made to accommodate our target users and the need for extending existing personae.

A persona is as effective as the data it is made up of, therefore data collection is a very important aspect of persona creation. Considering our target users are children with autism spectrum condition, interviews are not likely to produce any useful data, and observations are not likely to produce sufficient data. Therefore, we propose to supplement observational data with data collected from experts (teachers and researchers who have experience working with children with autism spectrum condition) through interviews and surveys. These experts are familiar with the characteristics, behaviours and day to day activities of our target users and are more capable of providing adequate descriptions. The use of experts as sources of data for building persona for children with ASC has been employed by both Leal et al. (2016) and McCrickard et al. (2013). Finally, selected personae for children with ASC gathered through literature review will also be used in this persona creation process.

The personae creation will start off by identifying behavioural variables through analysing the observational data. Since the personae to be developed will be used for personalising visual programming tools, observational data collected during our work on the accessibility of Scratch will be used, however only data for those participants with autism spectrum condition will be used here. The subjects that were observed will then be mapped to the identified behavioural variables to show each subject's behaviour across the identified variables.

The next stage will require data collection from experts. Individuals whose behavioural patterns have been identified in the previous step will be grouped based on behavioural similarities by the interviewed expert. The expert will then be asked to describe the main characteristics common across the individuals belonging to each group. Once the descriptions have been provided, the experts will be asked to go through the selected existing personae and identify those that closely describe any of the identified groups of individuals. If no persona is found that describes any of the identified groups, the expert will be interviewed to collect data for the creation of a new persona for that group. However, if a persona that closely describes a group is identified by the expert, the expert's opinion will be sought on necessary modifications needed to extend the persona into an accurate representation of the group that's fits the context of our work.

After interviewing all experts, the collected data will be analysed, and persona will be developed for each of the identified groups. A final validation process for each of the created persona will then take place by obtaining qualitative and quantitative expert feedback on correctness (using a four-point Likert scale) and consistency of descriptions (by requesting qualitative feedback). The experts will also be asked to provide any other qualitative feedback they deem relevant to make the personae better. The collection of qualitative data as part of the feedback is important to avoid problems similar to the one faced by Leal et al. (2016), who collected only quantitative feedback and found themselves with disagreements but not suggestions on how to resolve them.

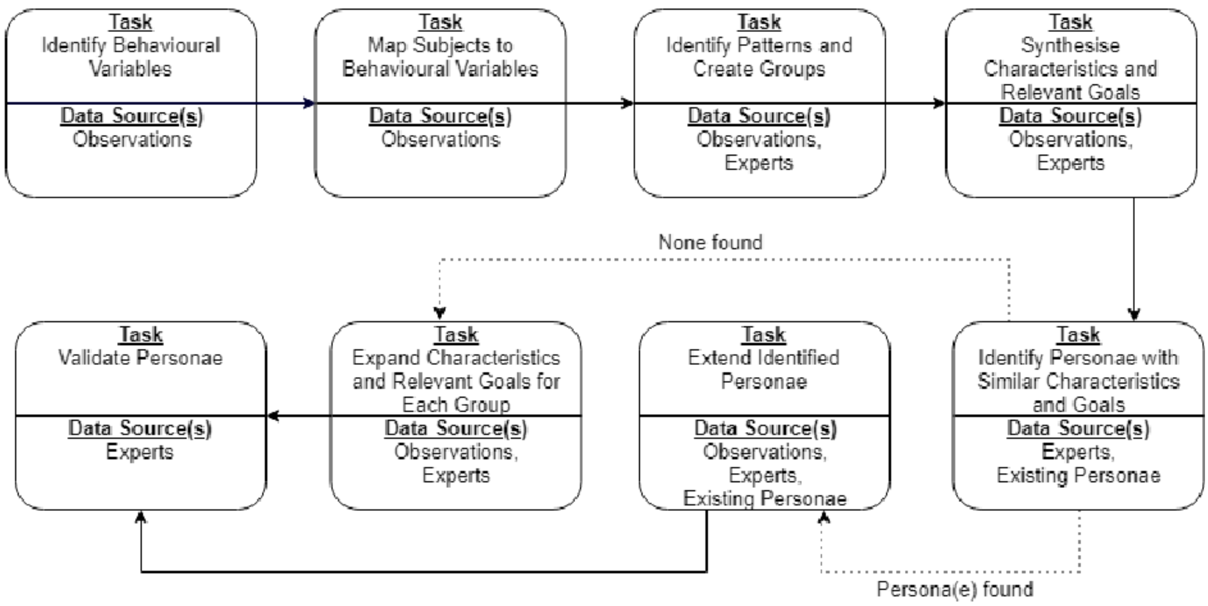

Figure 1. *Diagram showing the proposed method of creating personae for children with autism spectrum condition, based on the method outlined by Cooper et al. (2007).*

4. FURTHER WORK

Recruitment of experts will be conducted by reaching out to some of our previous collaborators within special education schools and research centers/groups. Other special education schools within the greater Nottinghamshire area are also going to be contacted about participating in the study.

Ethical approval for condcuting the study has been applied for through the non-invasive human ethics committee at Nottingham Trent University's school of Science and Technology. Once ethical approval is granted and participants have been secured, a pilot study will be conducted to validate the proposed method. Feedback from the pilot study will be used to decide on whether to proceed with the study using the methodology specified, or alternatively to make changes to the methodology.

5. CONCLUSION

We have presented the current state of the art for the creation of personae with Autsism Spectrum Condition (ASC) and have shown that very little work has been carried out using personae, and the methods for their creation are lacking. We then proposed a methodlogy for the creation of personae for children with ASC that is grounded in data. The method involves both the users (children with ASC) and experts (teachers and reseracher with experience in ASC). We have proposed the use of observational data of children with ASC since interviews are not considered likely to produce the rich qualitative data required here. Interviewing teachers and researchers to collect data that will be used to create detailed descriptions for our personae is also proposed. Experts will also be surveyed on the proposed personae to validate them for application. The survey will collect both qualitative and quantitative data to ensure useful feedaback is received.

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Assessing teachers' knowledge, readiness, and needs to implement universal design for learning in classrooms in Saudi Arabia

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ABSTRACT

UDL is used to design an accessible curriculum for all students with diverse abilities, including students with disabilities. UDL helps educators plan their curriculum proactively and address students' instructional, environmental, and other needs in an effort to help them reach their full potential. In 1990s Ann Meyer, David Rose, and their other colleagues, the founders of Center for Applied Special Technology (CAST), introduced UDL to improve teaching and learning' (Meyer, Rose, and Gordon 2014Meyer, A., Rose, D.H., and Gordon, D.2014. *Universal Design for Learning: Theory and Practice*. Wakefield, MA: CAST Professional. [Google Scholar]). UDL is based on three principles: 1) multiple means of representation, 2) multiple means of engagement, and 3) multiple means of action and expression. Using these three principles teachers can build flexibility in presenting the content, designing activities to motivate and engage students, and building in flexibility in providing options for the students to demonstrate their understanding of the content and address diverse needs of students in contemporary classrooms. In Saudi Arabia, the special education system is moving away from segregated setting towards inclusive education. This study explored knowledge of UDL of practicing special education teachers in schools in Saudi Arabia, and also sought information regarding their needs for successful implementation of UDL in classrooms.

The model of VR-Health

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ABSTRACT

The model of VR-Health is defined and a Virtual Reality Health Software development is written in this paper. The software demonstrates a potential usage of VR-Health. It could be a useful tool for GPs, therapists and patients when they would like to discuss or to check several tests e.g. X-ray, blood test or just a medical consultation in a virtual environment. Doctors, therapists could be in their own office and immerse in VR consultation room while patients could be in their home and also immerse in the same VR consultation room. It could be useful for different therapies for instance physicians as well as for psychologists.

1. INTRODUCTION

Virtual Reality (VR) allows computer based models of the real world to be generated, and provides humans with means to interact with these models through new human-computer interfaces. It can either be immersive, where the user feels physically present in the VR – typically using a head-mounted display –, or non immersive, where a handheld interface allows interaction with objects on a computer screen or on a smart device screen. Augmented Reality (AR) is when computer-generated contents are overlaid on a real world environment. VR and AR is widely used in healthcare (Yates at al. 2016; Tagayataya et al, 2016). Healthcare applications will be significant, it is clear, that the VR/AR technology goes mainstream. It is not just gaming and entertainment that are poised for transformation. Virtual Human Agents technology can be leveraged to improve engagement in teletherapy approaches between remote patients and care providers (Rizzo et al, 2014).

The use of virtual consultation is general in practice as GPs have used telephone consultations for over a century. There is a growing dissatisfaction with existing services on account of increased waiting times and shorter consultations. In 2016 patients were required to wait almost 2 weeks for a routine GP appointment, a 30% increase on the previous year, and a figure that is expected to rise to 17 days in this year in the UK (Bharadwaj, 2017). Likewise, GP consultations in the UK are far shorter than many other countries in the developed world, with 92% of consultations lasting less than 15 minutes (Kaffash, 2016). There has been much interest in recent years in the use of telemedicine for chronic disease management. In the study last year, patients experienced significant improvements in diabetes, blood pressure, and cholesterol control by interactions with their GP via video services and e-mail (Greenhalgh et al, 2016). Similarly, there is a place for virtual consultations in mental management, particularly among younger patients (Bharadwaj, 2017).

The problem of the increasing number of elderly people and their home-monitoring and rehabilitation will be also mentioned. In developed societies, more and more people turning older than 75 are likely to have some kind of impairment. This group will comprise 14.4% of the population by 2040, compared with 7.5% in 2003 – it is almost a twofold increase (European Commission, 2003). Another fact is that by 2020, 25% of the EU's population will be over 65 years. Money spent on pensions, health and long-term care is expected to increase by 4-8% of the GDP in the forthcoming decades. These expenditures will triple by 2050 (European Commission, 2007).

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