A Haptic Study to Inclusively Aid Teaching and Learning in the Discipline of Design.

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Abstract

Designers are known to use a blend of manual and virtual processes to produce design prototype solutions. For modern designers, computer-aided design (CAD) tools are an essential requirement to begin to develop design concept solutions. CAD, together with augmented reality (AR) systems have altered the face of design practice, as witnessed by the way a designer can now change a 3D concept shape, form, color, pattern, and texture of a product by the click of a button in minutes, rather than the classic approach to labor on a physical model in the studio for hours. However, often CAD can limit a designer's experience of being 'hands-on' with materials and processes. The rise of machine haptic[1] (MH) tools have afforded a great potential for designers to feel more 'hands-on' with the virtual modeling processes. Through the use of MH, product designers are able to control, virtually sculpt, and manipulate virtual 3D objects on-screen. Design practitioners are well placed to make use of haptics, to augment 3D concept creation which is traditionally a highly tactile process. For similar reasoning, it could also be said that, non-sighted and visually impaired (NS, VI) communities could also benefit from using MH tools to increase touch-based interactions, thereby creating better access for NS, VI designers. In spite of this the use of MH within the design industry (specifically product design), or for use by the non-sighted community is still in its infancy. Therefore the full benefit of haptics to aid non-sighted designers has not yet been fully realised.

This thesis empirically investigates the use of multimodal MH as a step closer to improving the virtual hands-on process, for the benefit of NS, VI and fully sighted (FS) Designer-Makers. This thesis comprises

[1] Machine Haptics is a term, used in this thesis, to relate to the study of machines for the augmentation of human touch in the virtual realm.

four experiments, embedded within four case studies (CS1-4). Case study 1and2 worked with self-employed NS, VI Art Makers at Henshaws College for the Blind and Visual Impaired. The study examined the effects of haptics on NS, VI users, evaluations of experience. Case study 3 and4, featuring experiments 3 and4, have been designed to examine the effects of haptics on distance learning design students at the Open University.

The empirical results from all four case studies showed that NS, VI users were able to navigate and perceive virtual objects via the force from the haptically rendered objects on-screen. Moreover, they were assisted by the whole multimodal MH assistance, which in CS2 appeared to offer better assistance to NS versus FS participants. In CS3 and 4 MH and multimodal assistance afforded equal assistance to NS, VI, and FS, but haptics were not as successful in bettering the time results recorded in manual (M) haptic conditions. However, the collision data between M and MH showed little statistical difference. The thesis showed that multimodal MH systems, specifically used in kinesthetic mode have enabled human (non-disabled and disabled) to credibly judge objects within the virtual realm. It also shows that multimodal augmented tooling can improve the interaction and afford better access to the graphical user interface for a wider body of users.

Acknowledgments

"It takes a village to raise a child." (African Proverb)

This ancient African proverb, for me, has been a metaphor to describe my journey through my Ph.D. programme. Although the road to submission has never been straight and easy, that road has always been lined with 'villagers' who have been cheering me on and supporting me mentally and physically to work through the bumps in the road.

Firstly, I would like to thank my primary supervisor, as without his patience, skilled knowledge and friendship in the harder periods this thesis would never have been possible. To my Principal Supervisor, Dr. Farshid Amirabdollahian, I do hope that the contents of this thesis sufficiently reflect all of your support and commitment to the overall study. The next thanks should be offered to my Second Supervisor, now happily retired from academe. For your part Professor Marcus Ormerod, you have offered positivity, energy, and support, as well as in-depth knowledge and expertise within the discipline of Inclusive Design. Professor Amanda Jefferies, for stepping in at the last hour as Second Supervisor with such a shared passion, I thank you too.

I would also like to thank Mr. Bruce Windle *(MA, MPhil)*, who sadly passed away in November 2017. Bruce was my mentor through my BA, and MSc, as well as my good friend and best critic. I think Bruce would approve of the inclusive nature of this study and admire the advanced technology used; he was always a self-confessed 'Techie'.

Thanks to all my friends and colleagues at Henshaws College, and the Design Group at the Open University. It has always been a pleasure and very humbling to work with you all and to thank you for all the 'Dad jokes', however corny they were. Thanks also to technical support given by Mike Bowler and Ryan Hayle. A million thanks to my mentor at the Open University Prof James Bowen. I thank you, James, for the care and considered support freely gifted to me to help me with this study program and, of course, for watching out for 'the banana skins' along the way.

Thank you to my close family, who have always been the loudest of all the 'villagers' cheering me on. Finally comes the last, but the hardest thanks; hardest as I never have found a way to truly say thank you that would be adequately meaningful. These thanks go to my husband and my four-year-old daughter, Jessica-Mae. There have been parts of the Ph.D. journey when I have had to work away from home, placing a lot of weight on to my husband (who is also studying and working full time). This time away took me away from 'Room on a Broom', the bedtime story which was the center of our mummy – daughter bedtime ritual. For this, Jessica-Mae, I am truly sorry, but thank you for 'putting up' with Daddy instead. The encouragement and love given to me by both these people have been inspiring, but the reward has always been my daughter's drawings and hand-written notes, given on my return home. Both of these people have always urged me forwards giving me the strength to commit to presenting the outcome of this work at conferences. Jessi, I hope this acknowledgment will make you proud in years to come.

“I am a visual person. I just can’t see.” (Peter Eckert 2011)

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Glossary of terms

AD	Audio Description
AMs	Art-Makers
ANOVA	Analysis of variance
AR	Augmented Reality
AT	Assistive Technology
AV	Audio Visual
GUI	Graphical User Interface
FS	Fully Sighted
EB	Early Blind
LB	Late Blind
M	Manual Haptics
Mdn	Median
MH	Machine Haptics
MMR	Mixed Method Research
NLP	No Light Perception
NSS	Non-Speech Sound
NS	Non-Sighted
NS, VI	Non-Sighted to Visually Impaired
PC	Personal Computer
RNIB	Royal National Institute of Blind people

RW	Real World
SD	Standard Deviation
SEM	Standard Error of Mean
SS	Speech Sound
TtS	Text-to-Speech
VE	Virtual Environment
VI	Visual Impaired
VR/Vr	Virtual Reality/or/realm.

List of Publications

The work that this thesis is based upon, is shown in following publications,

- Bowers,L. Hayle, R. Braithwaite, N. and Amirabdollahian, F. Haptic Prototype Assembly Tool for Non-Sighted, Visually Impaired and Fully Sighted Design Students, Studying at a Distance. EDEN June 2018, Genoa, Italy
- Bowers, L. Touching creativity; a review and early pilot test of haptic tooling to support design practice, within a distance learning curriculum. The Journal of Open and Distance Learning - Manuscript ID COPL-2016-0059.R2,
- Bowers. L. Assistive Technology Enhanced Learning (TEL) within distance learning. Shanghai Open University research fellow publications 2015.
- Bowler.M, & Amirabdollahian.F, (2013) Haptic cues for vision impaired art makers: 'seeing' through touch Procs (2013) IEEE Int Conf on Systems, Man, and Cybernetics: SMC 2013. IEEE, 2013. p. 547-552.. IEEE, Manchester 2014

1 Introduction

This thesis study is rooted in inclusive design thinking, which aims to aid the ‘Extra-ordinary’ PC users, enabling them to be ‘ordinary’ in their interaction with the virtual environment (VE). The thesis aims to make a contribution to knowledge, by undertaking investigations into the use of machine haptics (MH) for a specific user-group -namely non-sighted (NS) and visually impaired (VI) artisans /and / designer-makers. A specific haptic issue is addressed in this thesis: how haptic technology can overcome barriers of NS, VI user interaction with on-screen visual data. The issue is tackled by examining how well the selected device, Geomagic Touch™ (single-point device), can be adapted to add value to user experience and enhance touch perceptions of two specific user-groups namely (1) NS Art-makers (AMs) - Henshaws College, (2) NS design students -The Open University. Using a case studies approach the research programme will report on NS, VI user interactions with MH. A mixed method research (MMR) will be used to judge if adding a multimodal haptic interface will allow NS, VI users to work effectively with virtual on-screen objects.

1.1 Overview

For non-disabled, personal computer (PC) users today, conventional graphical user interface (GUI) is useful, but as it is predominantly vision and auditory led it offers a limited sensory engagement beyond that of sight or sound. This creates a barrier for NS, VI computers users, who are restricted to a singular sensory input, either via Braille keyboards (touch) or screen reading devices (sound). For NS, VI PC users, the facilitation of machine haptics (MH) has still to become recognized as a mainstream tool. However, from conducting a literature review of haptic augmented tools by NS, VI users, it was shown that haptics does have the potential to assist PC use by sight-impaired users.(Brewster S.A., 1994, Wall and Brewster, 2006)

This study focuses on a widening access to haptic technology for NS, VI PC users. Statistically, it has been shown by The World Health Organisation (WHO), that there are 253 million VI or low sighted people world-wide, with 36 million people registered NS (WHO, 2017, World Health Organisation, 2017) . Therefore, there is a substantial group of people who could benefit from working with digital platforms using haptic technology. One such group of people are the artisans who live and work with Henshaws Charity College for Blind and Visually Impaired, Knaresborough West Yorkshire. This group of individuals ranges in sight acuity status from NS to VI and from congenitally blind to adventitiously blind. In practice, the variety of artisans' variations in sight acuity means that staff and clinicians at Henshaws need to be dynamic and innovative in the provision of access to creative studio work for all artisans registered to Henshaws. All the people who attend Henshaws are either artists or 'Designer-Makers'[2] and as such known as 'Art-Makers' (AMs). Most of the work produced by Henshaws Studios is craft-based work, for example, felt artifacts, millinery pieces, jewelry etc. Many of the AMs are congenitally blind with little light perception, but a few have some eclectic vision with ocular assistances, for example, high powered magnifying glasses or high prescription spectacles. Henshaws AMs have joined this study as a focus group, and as such has played a large part in the inclusive 'user-led' input featured in Chapter 4 of this thesis. The AMs specifically targeted to take part in this study were selected due to their highly skilled manual craft skills and their refined tactile practices. The specific focus group selected were seen as an exemplary group with good insight and depth of the nuances of NS, VI creative tactile practice, as well as their interest in future technology trials. Through the work with AMs, this study sought to demonstrate how well haptics can enhance NS, VI user experience within the virtual realm (VR).

[2] Designer-Makers is a termed used to describe people who design and make work, and not just design work.

1.2 Machine Haptics

The study of machine haptics (MH) to enhance a user's interactions within the virtual realm has been developed and refined for over a decade. For non-disabled users, MH combines the 'act of doing' and experiential learning (Kolb and Kolb, 1984) along with the interaction of rich 3D graphics. NS, VI PC users need to be afforded assistive tooling to enhance their access to digital platforms. Therefore, through the experience of the augmentation of touch, they are enabled to use VR in an innate manner. Computer science research communities have been successful in showing how haptics holds the potential in the field of tertiary education, professional training, arts and design, surgical/medical and veterinary training practice

(Bach-y-Rita and Kercel, 2003, Barfield, 2009, Cheshire et al., 2001, D'Angiulli, 2011, Tokatli.O., 2017). The use has also been shown within the industry to enrich the users' experience within education, training, and development (Minogue.J., 2006, Levesque.V., 2008). Haptics have specifically been shown to aid NS, VI users, it was shown to increase access for NS, VI users to the web (Colwell, 2001, Colwell.C, 1998), as well as supporting NS, VI touch access to teaching aids for applied subjects for example, mathematical and graphical learning materials

Within these [i]studies, it has been shown that haptics holds the potential to widen the user audience to include NS, VI users as well as leveling the access to digital platforms.

1.3 User-led thinking

Despite the wealth of research disseminated spanning 20 years, and governing regulations for Assistive Technology (AT), there is a trend for unsatisfied AT users, to abandon the perscripted AT solutions. This issue of users abandoning technology, due to the lack of usability, is acknowledged in disabled services across the UK and shown as a waste of resources, time, effort, and money to NS, VI clinical services and their service users

(Phillips and Zhao, 1993). The lack of understanding about individual users' needs of AT has been disseminated as having an effect on user AT abandonment (Newel and Gregor, 1999). Greig, Keitsch, and Boks, (Grieg.J., 2014) state "…AT is a sensitive field. It provides the developers with complex design challenges with respect to functionality, usability and emotional aspects". Newell and Gregor state "that users can be 'Ordinary' and 'Extra-ordinary', certainly in '(dis)ability' terms designers are met with 'an extra-ordinary user', a user who wishes to operate in an ordinary manner, akin to the rest of society" (Newel and Gregor, 1999)

1.4 Distance learning technologies and the ability needs of the learner

The field of distance education provides learners' with access to rich digital and analog teaching and learning materials. The Open University (OU), (Milton Keynes) is one of the longest standing distance learning universities in the world *(founded in 1969)* current registration figures from data for the year 2017,show that there are 174,739 registered undergraduate (UG) and postgraduate (PG) students. (OU, 2015)

As part of its ongoing commitment to accessibility and TEL for distance learning The OU has created teaching technology which has achieved awards for its design and the technology standards of effective Technology-enhanced learning (TEL) systems e.g. The Guardian Teaching and Technology awards, awarded to the OU in 2017 and 2018. The enhanced learning technology used by The OU distance has afforded enhanced accessibility to be at the forefront of study for an 'open' student body[3]. The gap within the OU's current TEL offering is the wider introduction of sensory led TEL for **applied** studies for example, engineering and design modules. Haptic TEL has been overlooked by The Open University as a potentially accessibility led technology for applied disciplines within the past years. Added to this it is notable that the wider haptic research community has mostly limited haptic assistances for sight impaired users to the STEM disciplines or used it to increase

[3] An open student body is defined in this instance as students' body who have mixed ability needs, it also pertains to the level of learner on entry to the module of study.

the access to the internet for the non-sighted PC users e.g., science and maths/statistics (Tokatli.O., 2017, Colwell.C., 1998, McGookin.D., 2006). However laudable and useful previous works have been for The Open University sight impaired **design** students, studying at a distance, still require better access to engage with design module stimuli this is currently done via limited sensory channel of sound, thereby limiting students to a single sensory interaction device e.g. accessed via keyboard and/or PC mouse.

Although current modes of online interaction, for the distance design discipline, have been shown to be productive at the Open University, the wider body of the haptic community's research shows that using purely singular sensory interaction can create barriers to accessibility for particular groups of disabled students, particular reference has been given to, sight impaired, cognitive and motor function disorders (Amirabdollahian, 2011, Brewster.S, 2006, Bowers, 2013). Many distance learning institutes, such as the OU, have gone to great lengths to provide alternative teaching and learning material formats to increase access for minority disabled cohorts. For the non-sighted community of students there is still a way to go for distance learning universities to overcome the barriers to limited sensory interactions. That is to say, to offer all students equal or adjusted access.

Alongside its world-renowned provision of online learning, the OU offer learning which is termed as 'blended learning'. Blended learning is devised of physical hands-on face to face workshops, which are based in physical classrooms located around the country, and online study located in virtual classrooms. The blended concept being that students are able to attend physical workshops to improve tactile responses and making skills and blend this with their explorations of the theory of making and design through online theoretically based blocks of study. Through the use of hands-on processes engineering and design students, overall, gain a more in-depth understanding of how to use tools to externalize their project concepts (Liddament.T., 1990). In the

OU's physical workshops, students are requested to interact and assemble 3D concept models to better communicate their 'design thinking'[4]. Often the prototype models that are created in these workshops often use low fidelity models, which are a mix of low resistant materials for example paper or cardboard. The so-called 'sketch models', named as they are used in the early stages of the design process, can then be contextualised through scanning the paper models and resolving the 3D development work via digital graphics packages. The challenge of these type of sessions are that some students, particular students with physical, sensory or mental difficulties the attendance at the physical workshops can be difficult, this is mostly due to the individuals confidence and their physical access issues. These students can often subsequently struggle to keep up their hands-on skills development due to the missed attendance at the physical workshops.

Overall the challenge of an online design courses, in comparison to brick universities, is that often the distance programmes can offer limited access to hands-on workshop development sessions. Although the distance design programmes often offload the physical workshop imbalance by adding value to the students understanding of a wider theoretical base from the discipline of design. Commonly distance design students will be offered similar training in computer aided design (CAD) skills to that of brick universities. Both distance and brick universities will offer appropriate levels of understanding of the classical/historical design processing as well as a good depth of understanding of how students should respond to a design brief. The challenge for distance universities is not so much the lack of design teaching and learning more an imbalance of the physical hands-on elements which go someway to understanding the applied study discourse.

This research programme goes some way to address the lack of 'hands-on' distance learning interactions by introducing haptics to NS, VI and FS OU students. It aims to afford students with visual impairments and sight acuity issues better access to haptically enhanced TEL, which will complement the current teaching and

[4] Design thinking – is a term used is defined as thinking within the conceptual stages.

learning aims set within the programme of design practice at The Open University. The researcher argues, that by increasing NS, VI and FS students' hands-on experience via virtual augmentations, this will address the access to hands-on making processes for sight impaired learners. The study of haptics within distance learning contexts will go some way to offering sight impaired distance learning design students, a similar simulated virtual and physical modelling experiences, at the germinal stages of the design process, to that of their 'brick universities' peers.

1.5 Research questions and hypotheses

This research programme aimed to evaluate the potential benefit of haptic technology with existing assistive technologies and teaching software to increase access for non-sighted and visually impaired individuals. The following subsection presents the research objectives and the research questions with the supporting hypotheses of this study which support the thesis overall.

1.6 Research objectives of this study

This research programme's main objectives are to:

- Evaluate the potential benefit of haptic technology and to integrate the technology inclusively for non-sighted, visually impaired art-makers and fully sighted novice designers
- Define and utilize experimental methods (including usability methods) to highlight machine haptic (MH) touch perceptions for non-sighted, visually impaired and FS in virtual reality (VR) environments
- Evaluate touch-led skills shown by people who were once fully sighted (FS) and now are not, and people who are non-sighted from birth, to then use this knowledge to better facilitate kinesthetic haptic feedback to non-sighted, visually impaired and FS user groups.

1.7 Research questions

This study is set around three research questions. Below all the research questions are presented with accompanying H_1 and H_0. (RQ1 and 2, have been used in the empirical tests, case study 2 and4 and have been re-presented in the relevant chapters for reader reference),

- ***RQ1: Can a novel haptic design application, be used to assist non-sighted(NS) 'Art-Makers'(AMs) to interact with the virtual realm when aided by multimodal assistance?***
  - ***Hypothesis 1-*** The inclusion of a culmination of a) an embedded rig and b) multimodal virtual haptic force (with additional virtual assistive audio elements) will enable non-sighted users to achieve the standard (18.5seconds) Wade's peg-in-hole time of healthy participants.
- ***RQ2: Can a multimodal interface allow better access than manual touch to aid applied teaching and learning for non-sighted (NS), visually impaired (VI) and fully sighted (FS) design novices?***
  - ***Hypothesis 2-*** Haptics will enable a set assembly task within an acceptable time and with limited difficulty to the users.
- ***RQ3: Is a haptics-based system usable and qualitatively shown to be so, by the two main user groups under consideration, (non-sighted (NS)/visually impaired (VI) and sighted design students)?***
  - ***Hypothesis 3-****Haptic technology, used as part of a multimodal interface, can aid a creative 'sensory-led' process and contribute to more inclusive learning, for non-sighted (NS) art-Makers (AMs) and novice designers/ students registered on a distance learning programme.*

1.8 Thesis Framework

Figure 1, shows the structure of the thesis and how the chapters contribute to the research questions. As shown below chapters 2and3 set the context, followed by chapter 4 which reveals the methodology used throughout the research programme. Chapter 5 investigates a specific user group, Henshaws' AMs using Deep Dive testing activities, the second half of Chapter 5 and Chapter 6 investigate users' fine motor skills using the haptic device, and explore how NS, VI, FS users work with the device to assemble a prototype within set parameters. Finally, Chapter 7 brings together all of the work via a discussion and reviews the responses to the research questions and supporting hypotheses.

Figure 1, presents a thesis framework, this is a visual aid for the reader to review the flow of core research areas and how they are broken down. The diagram describes how the literature and research questions flows into the main empirical investigations in the analysis stages and out into the discussion and findings. The diagram also shows where the RQs and empirical study connect (indicated by arrows) the relevant elements in the diagram.

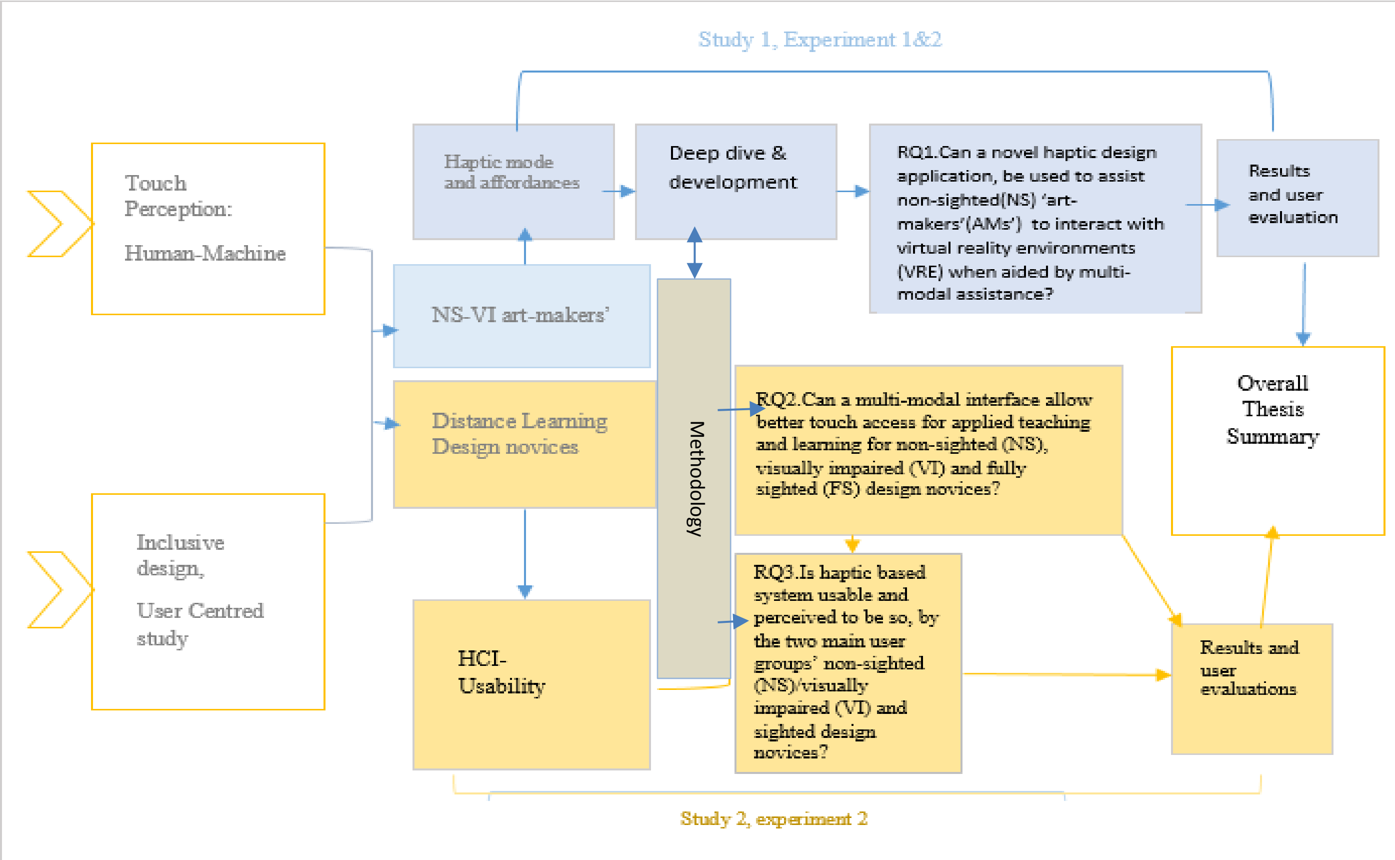

Figure 1 Thesis framework

1.9 Chapter overview and structure

Following on from the thesis concept framework, the following summarises the content of each chapter and how the chapters build to support the research questions and hypothesis:

- Chapter 2 offers the reader an introduction to blindness and visual impairment, emphasizing the human aspect from the condition. It also highlights how individuals, with sight-loss, manage their condition in their everyday lives. The literature in this chapter argues that well-designed AT can slow down the continuous AT abandonment and well designed, user-centric AT can improve the user's quality of life at best or increase their confidence in using the AT device with ease. The importance of designing inclusively is carried through to the haptic designer and reasoning is given through literature on why it is important to understand the user and how designers can affect better interactions with the technology to meet the user's wider needs.

- Chapter 3 investigates the background and history and workings of haptics (human and machine). It is designed to work with Chapter 2, to extend the narrative of human and machine. The chapter initially outlines the scientific domain of haptics interpreted as the human perception of touch and sensory system, with specific reference to active touch (kinesthetic touch). It also reviews the most relevant literature on haptics, the 'state of the art' applications of kinesthetic MH, with particular reference to single-point haptics used as AT. Highlighted throughout the latter section of the chapter are case studies of haptics aiding training and education.

- Chapter 4 communicates a general overview of the methodological and philosophical approaches adopted within the research programme. Included in this chapter are the explanations of how the philosophical and methodological approaches were selected, integrated and applied to a series of case studies CS 1and2, CS3and4. Each case study is presented as two sets of two-stage studies. Each set of case studies offer a combination of a preliminary study (CS1 and CS3) and a main experimental study (CS2 and CS4), a full description of each set is defined and the methodology presented in detail.

- Chapter 5, designed to answer RQ1, presents the first set of empirical case studies (C1and2). The chapter itself is presented in two halves, qualitative-led research §4.1, and quantitative-led research §4.3. The first half of the chapter (qualitative) describes an analog field study (also termed as Deep Dive study). This field study was designed to further understand the NS, VI, AM group as users, and used well-practiced inclusive design techniques. The second half of the chapter (quantitative) describes an experiment working with NS 'Art-Makers' (AMs) and FS control participants using a known clinical test, (aka Wade's Test). The test was designed to understand NS, VI and FS participants' efficiency when working with haptics via both modes (manual-v- machine). For Wade's peg-in-hole Test, six participants (n: 3 sighted, n: 3 non-sighted) were invited to join the experiment. The results were recorded as 'time' taken to complete the peg test, and a measure of 'collision' was also recorded and analyzed. Full analysis details are then discussed.

- Chapter 6 is designed to answer RQ2, presents a further set of case studies (CS3and4) and a new group of participants - NS design academics and students from the Open University. This chapter investigates whether it is appropriate to use MH to enhance NS, VI user experience in the first stage of the design cycle. This chapter again encompasses a two section template and a mixed methodology approach to collate data. In the first case study/ pilot test, entitled 'The Shape Assembly Test' (Mark 1) results are analyzed from three design academics from the School of Engineering and Innovation at The Open University, Milton Keynes. The outcomes from CS3 are then used to enrich the development of the interface to make it even more accessible to NS design students. Mark 2, is then presented to the student participant groups and a mixed method approach, using time and collision, is analyzed and discussed.

- Chapter 7, will summarise the potential as well as the shortcomings of using the selected haptic device. Chapter 7 will then review the empirical experiment work against the research questions, and discusses the agreements with either the hypothesis or with null hypothesis (H1and H0). Finally, this chapter reports on future work using MH for purposes of inclusive digital design practice.

- A full set of appendices is provided in this thesis, it contains samples of raw qualitative and quantitative data to accompany the empirical study work in Chapters 4, 5 and 6. An appendices contents list is provided for easier referencing.

1.10 Contributions to knowledge

The primary contributions of this thesis study are to the fields of Computer Science and Inclusive Design and Distance Design teaching praxis:

- The introduction of a realistic communication strategy between non-sighted groups and the researcher, which recognised a more holistic need of the user group. The strategies include the use of communication tools to aid smoother and balanced communication.
- The inclusion of 'user as expert', through a steady integration of the researcher's presence and actions coordinated with user observations and user input to their own creative needs and ability needs. Novel ethics development points created with Henshaws College teaching staff to work with Art-Makers in new ways for Henshaws.
- Novel haptic specific adaptions to user-interface of a clinical fine-motor skills trial e.g. Wade's test (1992), adapted to allow for greater access for non-sighted users to explore and navigate haptic cues within the virtual realm. Shown in Case study 2 – featured in published paper - Bowers. L. Bowler.M, and Amirabdollahian.F, Haptic cues for vision impaired art makers: 'seeing' through touch. IEEE, Manchester 2014
- Application of inclusive design theories and philosophies to the field of Computer Science, to draw attention to the motivations and reasoning behind accessibility to virtual and digital platforms.
- Empirical evidence to emphasise the use of touch-led performances for non-sighted users of virtual environment and objects therein.
- The instigation of inclusive design tactile assistances to aid non-sighted users exploration of a specific virtual environment.
- Opening an enquiry and increased discussion on the greater sensory augmentation to open, distance education to aid sensory impaired students studying applied subjects.
- Empirical study findings (case study 2), were able to offer evidence that haptic technology can support non-sighted art-makers to complete a given task within a shorter time frame than their sighted peers. published paper - Bowers. L. Bowler.M, and Amirabdollahian.F, Haptic cues for vision impaired art makers: 'seeing' through touch. IEEE, Manchester 2014
- Empirical study findings (case study 4), resulting in little difference in metrics between-groups (sighted and non-sighted) and between modes to complete a virtual prototype assembly using haptic technology. Bowers,L. Hayle, R. Braithwaite, N. and Amirabdollahian, F. Haptic Prototype Assembly

Tool for Non-Sighted, Visually Impaired and Fully Sighted Design Students, Studying at a Distance. EDEN June 2018, Genoa, Italy

Bowers, L. Touching creativity; a review and early pilot test of haptic tooling to support design practice, within a distance learning curriculum. The Journal of Open and Distance Learning - Manuscript ID COPL-2016-0059.R2,

2 Sight Impairment and Assistive Technology

2.1 Introduction

This chapter is one of two literature review chapters (Chapter 2and3) designed to contextualize and enrich background knowledge on the three core elements of this research programme. The core elements are **human (user)**, **tool (MH) and inclusive design-led HCI**. The first half of the chapter focuses on the human element and examines sight impairment and how people live with sight-loss. The chapter then reviews seminal works on the machine element, and reviews studies on AT and haptic technology specifically used to support NS, VI individuals to access and control digital on-screen content.

2.1.1 Semantics and terminology

According to UK Governmental guidance on inclusive language specifically used to refer to people with sight impairments, using the label ‘the blind’, is somewhat limiting and dehumanising for the individual. Alternative suggestions could be ‘people with visual impairments; blind people; blind and partially sighted people. From working and supporting artisans who are sight impaired, many preferred to refer to their functional sight, rather than their lack of sight, Art Maker 1 stated“ I prefer to say ‘eclectic sight’, rather than blind. For me personally using the word blind means I have been written off somehow..”(AM1, 2013).

Mentalhealth UK.org states that the social model of disability proposes that what makes someone disabled is not their medical condition, but the attitudes and structures of society (Health, 2018). A support assistant working with Henshaws College for Vision Impairment, Knaresborough, when asked about her theories on the inclusive use of the terms for sight impairment asserted “ I believe that sometimes the descriptions of variations of sight, allow able bodied people to further understand the person with sight impairments condition, in a clearer way”(Anon1staff, 2015) This may, to some able bodied individuals, seem like an exercise in semantics, but in fact some people with sight impairments feel that the language surrounding their condition can affect their confidence and even alter their feelings about their ability needs.

For the needs of this chapter and the wider study, the review of the literature has been limited to show how a person's sight acuity is measured for fuller effect, as well as a model which examines the usable field of vision. It also reviews AT which can assist the individual to maintain a good quality of life. NS has been used to clearly express when a person is without any form of sight. The term visually impaired (VI) has been used to highlight when a person holds some functional sight. All participants who are fully sighted will be shown as such FS, meaning that they have full vision without the need for glasses. This study is inclusively aware, inclusive of language surrounding a person's visual capacity as it is tied to a person/or/community and not just a clinical term.

2.1.2 Sensory perceptions and substitutions

"Perception is the process of obtaining, selecting, interpreting and organizing sensory Information". (Bishop, 1991)

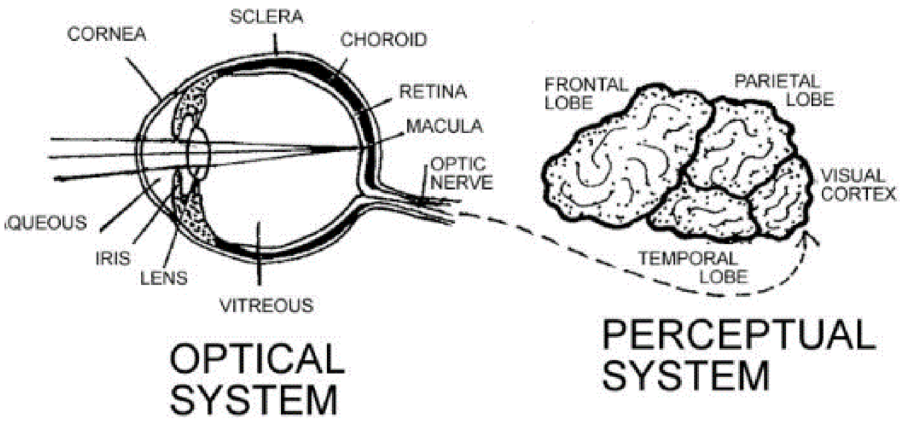

Figure 3 Visual system and perception system source tsbvi (Bishop, 1991)

Hersh and Johnson (Hersh and Johnson, 2005) state that the term perception can be divided into two categories:

- Exteroception - how the senses perceive external stimulus
- Interoception - how the senses perceive sensory information internally in the body, inclusive of proprioception (body position and movement).

'Perception' is a term which commonly describes how our sensory organs work together to perceive the world around us. How we interpret sight, sound, touch and smell are all tied to how our senses are externally stimulated, and the way in which a stimulus is processed and interpreted internally. Bach-Y-Rita and Kercel defer from the usual definition of losing a sense, they state:

> "Persons who become blind do not lose the capacity to see. Usually, they lose the peripheral sensory system (the retina), but retain central visual mechanisms. Similarly, persons who become deaf or are without balance usually lose only the peripheral structures relating to sound transduction (the cochlea) or positional orientation (the vestibular apparatus)."(Bach-y-Rita and Kercel, 2003)

The Bach-Y-Rita et al., quote is pertinent to this thesis, as a whole, as it enforces that although the person loses their physical capacity to see, or their window on the world, they do not lose their cognitive system which allows them inquiry and to explore their world. This study seeks to support NS, VI users to extend their inquiry and to support their need to explore by aiding their access to explore and utilize virtual objects in virtual environments.

2.1.3 Sight substitution

In 1969 Paul Bach-y-Rita et al., (Bach-y-Rita et al., 1969) were one of the first research teams to disseminate the phenomena of sensory substitution highlighting that should a person's sight diminish, it could be substituted through another sense. Since then work has been done to take this concept forward and create novel substitutions for pragmatic use for the NS, VI community.

More recently NS, VI people have selected sound as a substitute for sight, this is shown in audiobooks, DAISY screen readers [8]. A Daisy reader offers the user a computerized voice which transcribes all the text and verbally describes any imagery on the PC screen. Although this does offer NS, VI some form of access to the internet, or PC use, NS, VI users have found that the amount of text and imagery transcribed via DAISY readers can be quite overwhelming. Therefore users often choose to slow the verbal feed initially and when they become accustomed to it, they can accelerate the audio speed to adapt to their needs.

That said, NS and VI individuals have also shown time and again that the other main sensory substitute for vision is touch (Touch-Sight) (Bach-y-Rita et al., 1969, Burger et al., 1993, Heller, 2005, L´evesque, 2005). Bach-Y-Rita and Kercel (Bach-y-Rita and Kercel, 2003) go on to ponder the nature of tactile-vision sensory substitution (TVSS), they show that a change in one sense can re-map the somatosensory[5] system to allow the substitution sense to take on qualities of the lost sense. The more commonly known exemplar of TVSS AT is Braille, a way of laying down symbols in a bump relief format that can be read through fingertip traces of patterns on a page. (There is also an electronic version of Braille interaction – Braille Reader). However, there is a a low number of VI/NS individuals who are Braille literate, the reason behind this could be the effort and practice taken to learn and use Braille. Even now with a version of e-Braille, with refreshable text, the use of this is still slower than sighted individuals reading the same page. (Bach-y-Rita and Kercel, 2003)

[5] Somatosensory definition: The somatosensory system is the part of the sensory system concerned with the conscious perception of touch, pressure, EMED. 2017. *Somatosensory defintion* [Online]. Available: https://emedicine.medscape.com/article/1948621-overview [Accessed 09/02/ 2018].

2.1.4 Visual processing, and sight acuity

The World Health Organization [WHO] reports that there are 36 million people worldwide who are classified blind(World Health Organisation, 2017) Using the definitions of visual impairment as (a corrected visual acuity of less than 6/18 in the better eye) there are 253 million VI people worldwide. The WHO defines severe visual impairment as (a corrected visual acuity of less than 6/60 in the better eye), and blindness (a corrected visual acuity of less than 3/60 in the better eye or a visual field of less than 10 degrees). Acuity variations can stem from a person's physiological ability to perceive light and how the individual physiological system uses light perceptions to their best advantage, even a shadowy form can be interpreted as a form if there is light to outline the shadow.

- visual acuity: central vision, the vision used to see detail
- visual field: how much can be seen around the edge of vision, while looking straight ahead. (2016c)

The Snellen Scale is used to establish the acuity of someone's sight, the system works by a person being asked to read a chart of letters which get smaller towards the bottom of the chart. The standard 'healthy' sighted individual will be measured as 6/6, which converts to being able to read the bottom or second line from the bottom of the chart. A person with sight impairment/VI 6/60 converts to the top line or second line. Meaning that they can only read something at 6 meters away when someone with standard vision could read the same information at 60 meters away.(World Health Organisation, 2017)

Today's gold standard eye chart test is an ETDRS chart, which stands for Early Treatment Diabetic Retinopathy Study. This study was seen as a landmark study as it standardized visual eye test charts and so now every eye chart uses a form of ETDRS logarithmic setting. The following is a table which compares the Snellen and ETDRS charts.

Figure 4. Left figure, Traditional Snellen Chart showing the logarithmic style used (Gantry.D., 2017), right figure Alternative eye chart (Stevens, 2007).

The use of a logarithmic progression of letters in Early Treatment Diabetic Retinopathy Study (ETDRS) and Snellen charts is important as it allows for more accurate sight readings and sets standards across the countries who use the charts.

A person with no light perception (NLP) is quite rare, more often people with eclectic light perception (occasional forms of light can be viewed by the NS individual) but still these individuals are classed as clinically blind(2016c). The community of NS, VI are often erroneously considered as a homogeneous community. Contrary to this perception, the actual degree of blindness and the distinctness of light perception can vary from person to person and then altered by the surrounding environment the person is in at any one time i.e., 'working light perception' (WLP). The scale of sight acuity is measured from several distances: far, intermediate and close (Hersh and Johnson, 2005). There are varied scientific and high level engineered tools which can test the health (pressure, and retina health) of the eye.

2.1.5 Sensory compensation

Lévesque(Levesque.V., 2008) states that it is a common misconception for sighted people to consider that people who are non-sighted gain a heightened form of compensatory sensory perception. This means that once someone loses their sight it is believed that they instantly gain heightened sensory perceptions in their other senses, thus allowing them to hear better, smell better and have a heightened sense of touch. Lévesque argues that this is not so in most cases. NS, VI individuals can be trained to make 'better use' of the senses they have and to refine the use of those senses possibly to make them more sensitive than sighted people (L´evesque, 2005). However, Bach-y-Rita et al., state that due to the plasticity of the brain, some people can use sensory cues that would otherwise be linked to their missing sense. Bach-Y-Rita paper exemplified the known case of a teacher rolling a ball to a blind student, the blind student, in turn, copied the teacher's hands in readiness to accept the ball (Bach-y-Rita and Kercel, 2003).

Some people with low vision have been shown to use multi or dual sensory inputs more effectively allowing the individual to gain more information from the external stimulus in a short time (Levesque.V., 2008). Lévesque comments on sensory compensation, by noting the phenomenon of obstacle sense, where people without sight seem more sensitive to an obstacle in their way and have the ability to avoid it without too much effort (Levesque.V., 2008). However, he also notes that obstacle sense has also been shown in sighted people wearing blindfolds for any length of time. Warren states that blind people have been shown to judge a curvature of a space or object quite well, showing advanced exploratory techniques (Warren, 1978). The sensory compensation discussion could roll on, there has been some evidence of other parts of the brain being heightened (Burton.H., 2003) but no satisfactory scientific study definitively shows any heightening of other senses when sight is absent.

2.1.6 Dual/multi-sensory perception in sight loss individuals

Campus, Sandini, Concetta, Goi,(Campus.C, 2017) state that "Much evidence points to an interaction between vision and audition at early cortical sites". They go on to assert that "still little is understood about the function of these interactions". However, the fieldwork by Campus et al., goes on to further understand how audio functions can offer information about the location of sound and allow the individual to navigate to the sound and this has been shown in Early Years' education.

Obaid presents the idea that learning experience using all the senses is useful in reinforcing memory and has a long pedagogical history(Obaid.M.A.S., 2013). Obaid states multi-sensory learning has been utilized by teachers for non-disabled and disabled learners for a long period, as it works to engage all senses to better immerse the learner further into the task. Obaid's study worked with students (n=117) at sixth grade, studying mathematics, and tested the use of multi-sensory exercises with the test group (n=62) prior to an assessment exam, with the aim of increasing academic achievement of the test group. The control group (n=55) were not exposed to the multi-sensory exercises in order to compare the assessment scores between the groups. The results showed that students exposed to multi-sensory training showed more favorable results over the control group (Obaid, 2013).

Obaid is not alone in the exploitation of dual/multimodal senses; in the education of disabled students, this is a common theme. Yu.W, Kangas.K, Brewster.S, (Yu and Brewster, 2012) Mcgookin and Brewster(McGookin and Brewster, 2006) have all worked with dual senses (touch and sound) technologies for people with NS, VI. Yu and Brewster examined how to provide NS, VI individuals with an affordable web-based tactile and audio system. The dual input system allowed NS, VI users to interact with digital graphs and charts. Brewster and McGee(Brewster.S, 2006) have examined the use of haptic tooling in multimodal form, with what is termed as 'non-speech sounds' or 'earcons'[6] to provide assistance in areas where visual barriers became evident. The exploration of the introduction of earcons resulted in a finding that earcons were able to communicate more complex information more easily through structured sounds, rather than non-structured sounds. The earcon study also showed the need to connect more multimodal channels to graphical data. This afforded the user more multi-sensory feedback, compared to relying on a singular visual mode, which Brewster et al., claim can cause fatigue over long periods of time.

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[6] Non speech sounds and earcons - offer the user pure sounds, without any human speech attached, this is to increase the speed of the interaction by the user with the interface. A singular ping or beep sound is quicker to hear than a spoken word.

2.2 Living with sight loss

> Helen Keller wrote, “The sun does not shine for my physical eyes, nor does the lightning flash, nor do the trees turn green in spring; but they have not, therefore, ceased to exist, any more than the land-scape is annihilated when you turn your back on it.”(Keller, 1904)

Living with sight loss, or diminishing sight, can lead to the individual feeling isolated in their own body and shut off from society (Trust, 2009). After the words “… there is nothing further we can do…” from their Oph-thalmic consultant, patients are regrettably left having to deal with their condition in the current state, with the potential for it to worsen. The RNIB (2016c) describes coming to terms with sight loss as feeling the same as a bereavement. To that end, the RNIB has published an acknowledgment of the ‘grief-like’ phases of sight loss on their UK website to support people suffering from sight loss. RNIB report that individuals may not even fully acknowledge their struggles are a form of grief. The RNIB state that there are seven stages of com-ing to terms with sight loss, highlighting the physical and emotional distress that can be experienced through the journey of losing one’s sight. In the spirit of Keller’s quote (cited above), people living with sight loss have to cope and live with their sight loss in a visually-led world. But it is possible to regain life in an adapted form, and armed with the right tools and support framework, individuals can gain back a standard of quality in their lives.

> The variety of sight loss and differing experiences of sight loss mean that people will not identify themselves under one unifying label. Some may simply refer to themselves as having ‘poor eyesight’, ‘poor vision’ or ‘blindness’.(2016b)

There is currently a widening body of knowledge of sight loss, but more importantly how it can affect and impact the individual’s everyday life inclusive of their needs both socially and emotionally. One of the leading bodies, amongst those who are proactively engaging people with sight loss and attempting to understand the coping strategies for sight loss, is The Thomas Pocklington-Trust (P-T)[7]. P-T is a recognized body which funds research and publishes work that first includes the socio-model of the individual, before mentioning their disability. P-T is one of the bodies of experts, in the UK, who are changing paradigms of how individuals can be supported to enable them to live with sight loss. The Trust has published various reports(2016b, 2016a) identifying different stages of a person's life with a degrading sight loss. This type of study highlights weaknesses and gaps in the current wider support given via different support bodies.

In their 2009 The Changing Needs of Sight Loss publication (Trust, 2009), P-T reported that their subjects conveyed a strong feeling of subjects not wishing to engage with former sight-based activities, for example, watching films, working with the computer. From one example subjects communicated that their sight loss resulted in a decline in taking part in enjoyable activities such as reading, watching TV, cooking or driving, which had an effect on their whole demeanor and confidence (Trust, 2009). Without support interventions, these people had simply erased these activities off their list of things they were able to do and potentially became depressed as an outcome. It was also noted in the report that most Ophthalmic services appeared to operate on a 'they-will-contact-us-if-they-need-us' basis. Although this was offered with all good intentions it was premised on the notion that NS people, who felt cut off from society, would contact the service for help. When asked by the Trust, 'when would you go to the services available for help?' most subjects responded that they would not reach out to professional services, as they did not know how they could access help and what help they could ask for to consequently help themselves. The Trust Report disseminates the misalignment of users' needs offering a timely reminder of the need to intervene at the right time before the individual goes beyond help.

[7] The Thomas Pocklington (Pocklington-Trust) Trust is a charitable body that works with individuals outside of the clinical interventions. They employ experts and work on primary white paper work, pushing the boundaries of living with sight loss and aiding rehabilitation.

P-T also reviewed user-group perceptions of their own disability and their view of the general public's response to blindness and VI. Users responded via independent research reports on the following four areas:

- Access - Participants held strong views on access to the environment, access to information and public transport. The group advised that social health policies such as the public 'smoking ban' resulted in extra street furniture which acted as obstacles for NS, VI to navigate.

- Attitudes - Participants felt attitudes about sight loss could be improved as they played an important role in living with sight loss. The attitudes of those without sight loss were described as variable, but often problematic and patronizing for example, unwanted or inappropriate, almost intrusive, offers of help from the public.

- Daily Life - The 'little things in life' were a constant source of frustration for participants. NS participants felt that more could be done to share information on low or non-tech strategies invented by NS people to overcome small frustrations, for example, using a fingertip to gauge the levels of warm liquids in a mug rather than using a gadget which cost time and money.

- Support - Support was needed from a variety of sources (such as close family and social services) and in a variety of forms (social, material and financial). Environments that were inaccessible to people with sight loss often created different support needs, as did the person's age and ability. (2016a)

The results from P-T Research Findings 29 (PockingtonRF29 2016), show that users would like to have more of a voice and be informed about researchers who are carrying out research to support the VI community.

Dissemination of user-centered research should be wider spread and blind charities should support the communications of the latest research issues. New ways to discuss sight loss should be widely advertised to the general public to bring society up to date on inclusive terminology. (2016a)

2.3 The Visual functional model

For the purposes of working with participants in Case study 1 (AMs, Henshaws charity), Corn’s Visual Function Model (Corn.A.L, 1983) became a useful reference source, as it defines sight loss/impairment from an educational viewpoint and rehabilitative viewpoints. Corn’s model states that when considering a person’s eye function, there is more than a person’s visual acuity which can affect their overall vision. Corn’s model shows other factors such as environmental cues and the character of the individual can affect an individual’s capacity to maximize visual function. The Visual Functioning Model has been cited as a ‘tool’ to be used in conjunction with clinical acuity measures to support and rehabilitate a person’s sight.

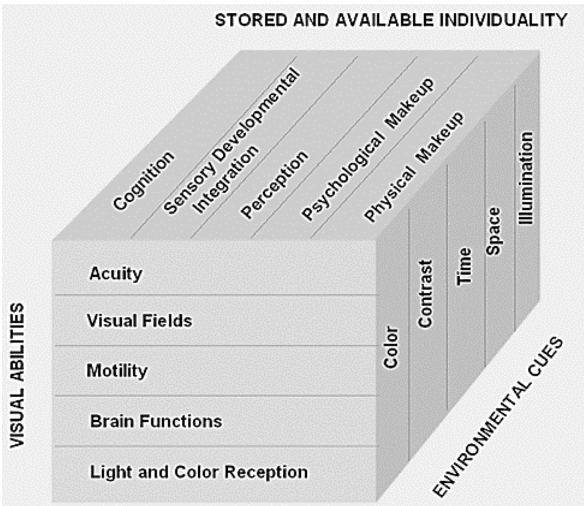


Figure 5 Corn’s Visual Functional model (VFM) (Corn.A.L, 1983)

The is a 3D layered model but can be shown as three interconnected titles; 1) visual abilities – relates to the physical visual abilities of the individual, 2) stored and available individuality – past experiences and how the individual relates to new sensory stimulus and 3) environmental cues – relates to the physical properties of

RW objects. Within each of the three labels of the model are further concepts to consider when assessing an individual's needs for better visual function.

Corn's model holds a great depth as a reference and although it was created over thirty years ago it appears to be the only model of its type to research 'the person' and to do so one must go beyond their physical ability. It examines visual deftness and adjusted settings. The concept of being able to develop an individual's ability to use what vision they have to better their interaction with learning and development is more than noteworthy and holds inclusive intent at its heart. For this programme of study, Corn's model has also been used to form a reference point to consider when working with people with sight loss. This study has never aimed to provide a tool which could rehabilitate the sight loss participants; instead, it offers a tool which has the potential to assist the augmentation of multimodal touch.

2.3.1 Cross-modal perceptions and cortical stimulations in non-sighted and visual impaired

In the last two decades, scientists have started to understand that the human brain is not statically wired to specific cortical areas and can actually rewire itself resulting in an NS person being able to utilize some areas of visual cortex to assist with other sensory input. The study by Olivier Collingnon, Voss.E, Lassonde.M, Lepore. F (Collignon.O., 2009) showed that there is definite evidence of the visual cortex in the brain being utilized alongside other sensory inputs, such as audio. The study requested NS people to listen to three different audio clips. Whilst listening they were being scanned via magnetoencephalography (MEG) to visualize their cortex activity. Each audio clip was audibly distorted further from the last, NS participants visual cortex was shown to be engaged when the speech on the clip became more audible. Collignon's work seems to suggest that the brain can readily utilize seemingly closed down cortical areas to assist in other sensory tasks. Such brain plasticity has been suggested by Collingnon et al., to have the potential to affect the spatial understanding of sounds like the brain plasticity, shown in their subjects' hints that there are more dynamic effects and greater potential in an NS brain than is currently recognized.

Sterr, Müller Elbert, and Rockstroh (Sterr et al., 1998) state that a healthy adult's nervous system has the capacity to change according to the environment. Sterr et al., showed this, through magnetic brain scans of

Braille reader subjects using three fingers, 1 finger and a control group, with no Braille skills. When fingertips were stimulated the somatosensory cortical in charge increased to mirror the stimulation and complexity of touch. Burton et al.,(Burton et al., 2006) state reading Braille has been shown to activate the visual cortex in blind people. They studied a matched user group of (0-5yrs) of late blind and early blind children, VI and sighted control. The subjects were asked to touch read raised letters, whilst images of the brain were recorded. Early NS and late NS participant groups both showed increased activity in the visual cortex areas and VI showed more dynamic activity across the visual cortex areas. (Burton.H., 2003)

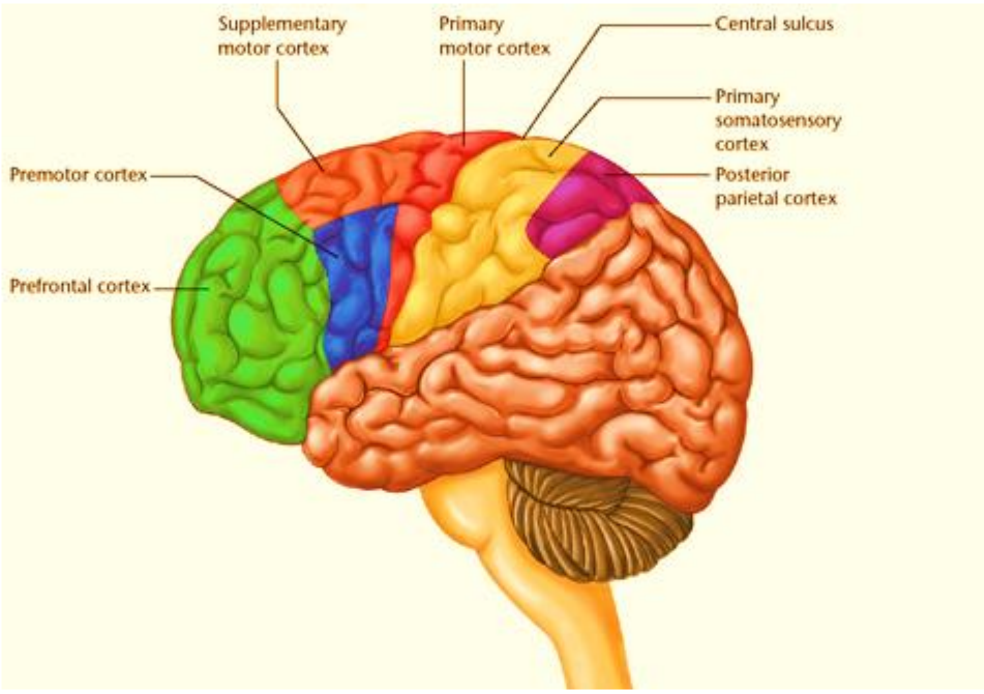


Figure 6 Brain Cortex (Burton.H., 2003)

2.3.2 Spatial understanding in non-sighted and visually impaired

The recognition of the body's location in space is considered to operate on two forms of internal spatial understanding Firstly, a route representation using the standing bodily axis as an internal frame of reference. Using sight, a person can understand a route directional reference from a standing central point for example left, right, forward and backward (Bladdock, 2010) The second form of spatial recognition is based on abstract topographical directional understanding. For example, working to a fixed co-ordination east, west, north, and south a person has the ability to understand topographical information and to use it to walk in the right direction (Thinus-Blanc.C, 1997)

Schmidt, Tinti, Fantino, Mammarella, and Cornoldi (Schmidt et al., 2013) acknowledge the debate on vision domination to understand recognition and ask whether early NS have difficulty remembering spatial layout as they do not have the visual ability to scan their environments. Schmidt et al., seem to assert that there is a causal relationship between early blind not being able to see the environment to obtain survey mapped detail and so information, whereby they cannot use the information as a form of mental reference, cannot aid route representation or survey understanding. Of course, it is important to ascertain a strategy that allows the non-sighted, whenever their onset of blindness is, to walk as autonomously as possible within an environment. Prior to any guide dog assistance, the prospective owners have to work through a rigorous training programme to walk unaided except for a cane. Of course, there is the case that a blind person may have an excellent confident traveling expertise, and would thereby be quick to take on further strategies for spatial understanding. Schmidt et al., the study sought to understand whether NS people could understand route versus survey information to aid directional understanding. The results showed that those NS participants using survey via wooden (tactile) maps gained better results than those given purely verbal route based directions. The discussion of results in this work was intriguing showing that NS people who were confident and used to autonomously moving around were equal to the results achieved by the blindfolded sighted control, and the results were much weaker from NS people who were not used to moving around without an aid or another individual to support them. This appears to suggest that the more confident the NS person is about traveling or moving about the abler they are to convert directions or tactile imagery to mental mapping to enable better directional recall.

There is also the case that some early blind people could use another sense such as audio to echolocate their location in space. Echolocation works by a blind individual using a specific type of click or hum with their mouth and listening to the echo recall bouncing back from objects around them. This allows the individual to understand where they are in relation to other objects their sounds have bounced back from. A paper by Claire Wilson(Wilson, 2017) explains just how capable some individuals can be at echolocation. She states that some are so proficient they can draw a sketch of a room after clicking their way around it, or even go mountain biking along unfamiliar routes. There is quite a bit of debate by scientists as to which sounds can ascertain the most efficient location feedback, and why some people are more proficient at this than others. Some scientists are analyzing how they can lift the techniques of some NS people to direct others on the technique. Daniel Kish, a famously recognized expert (by the New Scientist) in echolocation would agree with the dissemination of echolocation learning. He states "You can tell a tree from a post and from a human". Kish believes that it takes only 2-4 days to teach early blind children to begin to use echolocation techniques and this enables them to grow up without an aid or a human assistant. (Wilson, 2017)

2.4 Digital access and using spatial cues

Navigating around a GUI could be said to be as difficult for NS, VI people as orientating around an RW environment. Even with a screen reader technology, without some form of visual recognition of a cue marker, it can be difficult for an NS computer user to understand their location on the screen. This can make activities such as web browsing difficult. In her doctoral thesis and subsequent papers, Chetz Colwell (Colwell, 2001, Colwell et al., 1998) asserted that visual web interactions were causing accessibility issues and she responded by translating the visual imagery into imagery which could be interacted with a haptic interface which presented users with a series of textures. By acknowledging the varied facets of usability guidelines and Governmental policy Colwell imparts a Designer's interface guide to enable better accessibility via touch to increase web access to NS users. Colwell stated that she understood from her doctoral work that haptic interfaces could offer some form information to interpret imagery if the tactile content is formatted into columns or framed data so that NS, VI users could navigate with tangible well organized tactile objects on the screen.

Oliveira.J, Guerreiro.T, Nicolau.H, Jorge.J, Gonçalves.D, (Olivera.J., 2011) conducted a research trial examining (n=13) NS, VI participants to use one and two hand contact (finger-tip touch only) with a large interactive tablet. Users touch pathways were tracked and users were requested to find objects. Analysis showed that when using large tactile spaces NS, VI lost their spatial understanding without any additional feedback, e.g., voice, sound etc. Some users refer to their own tactics to locate the object, for example, working into the center. Thus, Oliveira et al., make the suggestion that when working with NS, VI people on location or spatial understanding tasks focus needs to begin at the edges or the far corners of the tactile tablet/object. This is where this group feel it most natural to begin tactile explorations. This finding concurs with the authors' own observations of NS, VI artists manually using landmarks within their own desk space. Often AMs were observed, using the edges of the workspace as landmarks and locating a home cue usually in the bottom /top left-hand corner of their workspace. The home cue was usually a heavy object, a weight or a stone. The NS, VI set up their own space and would operate in this fashion prior to any form of creative processing.

2.4.1 User-led/inclusive design approach

When approaching the issue of design for human need, it is important to be mindful of the heterogeneous nature of the community of people with the need. It is imperative to examine and investigate the clinical and social requirements surrounding the user's life. In short, it's important to examine the whole person as well as the medical condition. For example, someone who has a sight condition could range from low vision corrected with spectacles to no light perception (NLP), otherwise known as clinically blind. Some individuals who have smaller levels of sight loss could have a condition which is degenerative over time. Others may have multi/dual-sensory impairments, for example, Deaf/Blind or they may have secondary conditions alongside the sight loss, for example, neurological issues and fine motor weaknesses disabling their sense of active touch. The Designer should become aware of the levels at which a person's overall capabilities can determine their use of a product or object, rather than their disabilities.

The age of a person's sight loss or visual impairment has been shown to alter the individual and change the way they respond and use their other senses or how they map imagery inside their mind. For example, someone who has a memory of full sight but then loses their sight could hold a clear memory of how an object or environment looks and therefore this could be drawn upon to aid cognitive mapping.

Newell and Gregor (Newell and Gregor, 2000) have suggested that this type of design thinking requires a new paradigm termed "User Sensitive Inclusive Design". Newell and Gregor's concept was to offer best practice design thinking for all, to compromise slightly on the product design so that, while the design retains the functionality required by people with disabilities, it still appeals to a wider audience(Newell and Gregor, 2000). Although this concept has its roots in universal design, the core concept is the same as a user-centric process.

Fabrizi and Bosher (Fabrizi, 1995) reviewed electronic book interfaces for blind and partially sighted users, their results showed that over a million blind and sight-impaired users are turning to use e-books over Braille. The main reason for this is Braille is seen to be cumbersome, expensive, bulky, and require large amounts of storage to store whole books. Electronic books offer a more effective medium for blind and visually impaired to access audiobooks and to use a lightweight high capacity technology. However, Fabrizi and Bosher (Fabrizi, 1995) acknowledged that the e-book user interface could be developed to increase more user-led interactions. They argue that by increasing access through better orientation, data filing and location of media would not only improve the interface for blind users but for everyone. Using a system which Fabrizi et al., call Access Technology means that users can use a screen reader application which alters the colors, text size, and rendering speech audio, resulting in a more comprehensive experience for the user. This type of HCI work is cyclical - it builds on the platforms of previous mainstream technology and adapts them to suit a sensory impaired user's needs, but this work is a two-way process and it facilitates the user-adaptions to go back into the mainstream market and to increase more accessible interactions for all.

2.5 The theory of affordances

Everyday objects hold affordances which become more apparent as we interact with them. Through sight, sound and touch we can identify objects, establish the properties to be exploited and establish its use in real time. The psychologist James Gibson determined the affordances of an object in his seminal 1979 article, The Theory of Affordances (Gibson.E.J., 1979). In this article, Gibson offered that an object holds affordances which allow the nature of the object to be better understood. Particular functions of an object can 'speak' to the user on how it is best utilized in the most efficient way. In his later works, Gibson expanded on the theories of affordances by highlighting objects in everyday life that could be designed to instantly highlight the nature of use. The example given is a ridged metal bottle top which describes the orientation/direction to twist the lid. A door handle and a door hinge allow for a user to understand whether to pull or push the door. Moving Gibson's Theory on, to more current times, this type of model has framed the concept of non-verbal communication of an object. Common everyday objects, can offer affordance cues which enable better use. Inclusive Designers, such as OXO UK[8] are expert at designing the best object affordances for user-need which then makes the object user-friendly, innate and safe to use for everyone's needs.

Marieke Sonneveld and Hendrik Schiffersen (Sonneveld.MH and Schifferstein, 2008) examine novel sensory frameworks to guide product Designers to produce objects which offers a tactile and even emotional reaction. They reflect on the fact that in other sensory engaging industries, such as food and drink, products are designed to match the person's multi-sensory input and offer them a plethora of emotional engagement that is not yet used fully in the design industry. To work with sensory engagement, specifically touch, could allow users to feel more connected to the product, and thereby working to a notion that Designers could consider

[8] OXO UK – are a UK based inclusive design product company. Good Grips are a product range which were designed to support users with arthritis.

products which could become easily understood through more of the human sensory engagement. Sonneveld et al., working hypothesis is that people need to feel understood and their needs accepted and this should be shown through the design of the objects that surround them (Sonneveld.MH and Schifferstein, 2008). This seems to suggest that the gap between 'user – object' could be bridged by 'designing in' more sensory capacity. This then feeds further into the 'universal user' category, and hints at a more innate user directive and less aesthetic directive. This directive, of course, is dependent on what the object is for and how the user is supposed to use it. There are some objects used in daily life that are designed to offer emotive responses through tactile feedback for example, blankets, clothing, and soft furnishings, whilst other objects used in daily life, hold a purpose and use which can be further determined through tactile and visual interactions, e.g. packaging, technology, and utility objects. If an object is to hold the title of 'universally' designed (UD) it needs to be accessible to all users, even if that means the object affords each user a slightly different way to interact and use it.

2.5.1 Non-sighted and visual impaired AT and Abandonment

One of the founding fathers of AT for NS, VI communities is Ray Kurzweil (Kurzweil.R, 2018), an innovative engineer who was the first to develop the 'reading machine' which preceded screen readers. The machine was developed early in 1980s and worked by exchanging print for speech. The users lay printed text down on to a scanner surface which is then read with 'Opticon' technology and transferred to 150 words per minute audio text.

There are a wide range of assistive technologies (AT) designed to assist people with low or no sight. This section reviews the touch and audio-led technologies which are more aligned to this study. The main categories of AT are sensor-bridging technologies that can aid mobility and text-speech, and navigational aids, which combine dual or multiple sensory inclusions.

2.5.2 Being 'ordinary' and assistive technology 'hacking'

Despite the widespread proliferation of AT, it is commonly accepted that not all AT fits the individual's present and on-going needs and not all AT Designers work closely with the user, using 'best practice' inclusive approaches and user-centered principles. Given the choice AT users appear to choose more prosaic routes of assistance, including self-fashioned assistive devices, or simply adapting mainstream products to suit their own needs. This process, sometimes called AT -hacking', can afford the AT user more of a connection with the AT itself. However, the researcher would argue that for many AT users this is not a concept that would or should ever be considered as we should strive for the AT to be usable from the day it is procured and delivered to user. However, for some confident AT users, those who may hold the skills to adjust the AT, then AT hacking could have some resonant source of innovations which could be fed back into the AT design community to increase a more common understanding of real world AT user needs. MIT have previously endorsed the process of hacking, this was shown by their numerous examples of credible hacks in the ATHACK conference 2015. MIT PhD Student Ted Burnell stated that "We don't want to just listen to (client) and then run away to work on it any more than s/he wants to be the oracle of what is needed with no input into how it's done," he adds " Design is a conversation" (Sampson.P, 2015). The researcher would argue that the key message here is 'balance', the balance of designer *(skilled professional)* and user *(expert)* and the nature of the balance between the stakeholders can offer a result of a user-friendly, innovative, AT product with a more tenable lifespan.

The provision of AT devices is ostensibly to assist and improve the quality of the user's life, to offer independence for the user and provide an easier relationship with their own environment. However, if the user doesn't feel physically in tune or emotionally connected to the AT or the AT does not function the way the user expected it to then this can lead to the user abandoning their AT, even if the abandonment goes against medical advice or even longer termed therapeutic values.

R Verza, ML Lopes Carvalho, MA Battaglia and M Messmer Uccelli (Verza.R, 2006) offer that even at the initial selection and evaluation points, the abandonment cycle[9] can begin if the selection and user needs analysis is incomplete. The staged abandonment cycle can begin as an effect of little or no AT assessment of user's needs or lifestyle. The effect could be that the users become despondent with the lack of usability or malfunctioning technology and this can then hamper the user's confidence, and impinge on their independence in their daily life. Add to this a lack of training of the AT, inclusive of training the users next of kin/wider family, then this could be said to be another leading factor of abandonment of AT. Phillips and Hongxin Zhao (Phillips and Zhao, 1993) state 29.3% of all AT devices (UK) were abandoned within the first year. Mobility aids were more frequently abandoned than other categories of devices, and abandonment rates were highest during the first year and after 5 years of use. The main cited reason shown by Philips et al., is the lack of user-centric integrity, thereby leaving the final AT product less than user-friendly at best, and at worst offering the user no workable form of supportive assistance. Other responses covered the lack of ease of use, lack of ease of device supply and a change in condition resulting in varied needs which the AT was not designed to meet. One of the main points is to strive to be 'person-centric' and allow the user to guide the function of the aid device. Cook and Polgar (A.M and Polgar, 2015) offers five key principles to successful provision of AT.

1) The process is person-centred not AT centered.
2) The outcome is enablement of participation in desired activities
3) An evidence-informed process is used for service delivery
4) AT services are delivered in an ethical manner
5) AT services are provided in a sustainable manner

Cook and Polgar highlight here the need to maintain a close connection with the user of the AT to avoid wasting time and funds on AT which is not sustainable or useful. It is important to note that just because AT

[9] The abandonment cycle is presented as Lack of consideration of user opinion in device selection, poor device performance, change in the needs of the user, lack of training,

devices/technologies have been highly developed with blind and visual impaired in mind, if the technology is too complex or stands out as being used only by impaired users, the sight loss community may not fully appreciate or fully accept it. It may only be the most interested or techno-savvy individuals, who would persevere with AT. Lèvesque states users who succeed at learning and making effective use of complex aids may be the exception rather than the norm (L´evesque, 2005). The sight loss community usually exist on 'word of mouth' or clinical professional prescription for AT devices. This could limit people with sight loss in their access to marketers with potentially real and usable /accessible features. Added to this a large number of people with sight loss in the UK are within the bracket of an aging population, (75-85 yrs *n>500,000 UK estimated, in 2016*) (World Health Organisation, 2017) and as such it is suggested that this group of people may be wary in their use of complex new equipment when the answer may be simple design solutions.

Lèvesque (L´evesque, 2005) offers the following recommendations for inventors of AT for the next decade: collaboration between the blind, rehabilitation and research communities is crucial. He goes on to say that the collaborative design process is the best hope for assistive devices of practical use. Designers of innovative devices must be ready to face a natural opposition to changes that go against conventional wisdom. This statement is in line with many inclusive design principles', by embedding a 'people first' premise designers can expect to learn more about their users and gain more chance of providing a designed object fit for purpose. However, inclusive design is more than this; with the right methodologies an inclusive Designer should use their problem-solving ability to bring extra added value to the user's needs and aiding the user to achieve tasks that they never thought they would achieve. Lèvesque concludes by stating it must be remembered that no blind person can speak for the entire community. The opinions and needs vary between individuals. (L´evesque, 2005)

2.6 It's 'normal' to want to be 'ordinary'

In today's society how people use technology, and specifically which technology they use, speaks about their social status and their values in life. Younger generations, whatever their disability, value technology which gives them a positive identity and affords them a sense of 'fitting in', or 'being normal'. Such is the desire to 'be normal' and not seen as having extra needs that many VI young people believe that to 'fit in' is as important as the technical capabilities of the AT. Söderström and Ytterhus state "Even though both ICT and assistive technologies are perceived as identity markers, their symbolic values are inherently contradictory". They go on to describe how AT is inherently medically linked and as such shows a user to have a form of dependence. If the user is a young person conscious about their self-identity, then AT allocation becomes a sensitive issue (Söderström and Ytterhus, 2010). For younger people AT can be viewed as a stigma, communicating their restriction or vulnerabilities, rather than their abilities.

One of the assertions for adoption of this technology was that the lines between mainstream technology and assistive technology are blurring, and designers are now becoming aware of more qualitative based notion such as disabled users wishing to be seen as 'ordinary', and using the same technology as their friends, peers or family (PocklingtonTrust, 2016) From the author's own experiences, young adults with sight impairments have refused to use magnifying glasses to read on public transport, as it is reported that it opens them to ridicule or mockery. Even if they enjoy reading at home they prefer to listen to the book via audio rather than use the allocated AT. Comments from the individuals observed in Henshaws Charity included "I think the magnifying kit makes me look old *(laughing)*" and "Yeah, it's what [sic] grannies use (sighing and laughing)" *(see Appendix A1)*

2.7 Technology and exclusions

> "To blind and nearly blind persons, computer access is severely restricted due to their inability to interpret graphical/visual information… A blind person often accesses visual information through a process involving a sighted person who converts the visual image into a tactile or verbal form. This obviously creates a bottleneck for any blind person who wants access to visual information and it also generally limits his or her autonomy". (Sjostrom.C, 2002)

Over the last decade *(2007-2017)* society has borne witness to huge changes in digital and machine-based technology, and its ability to enrich everyday life. The World Wide Web has grown in popularity exponentially for example, 1995 =16 million users - Dec, 2013 = 2.8 billion users (Internet world stats, 2014). PC users worldwide interact with the internet and PC screens via the Graphical User Interface GUI[10]. The GUI offers users icons, active buttons, etc., to guide users in their orientation of the virtual space. As GUIs are mainly visually led or predicated to work with sight or sound, it therefore diminishes the access to the GUI for users without the use of one or both of these sensory channels. This can offer an obstacle particularly to people with NS, VI whose sensory interaction is audio, or audio and touch.

Graphical user interface (GUI) offers users added value through rich aesthetics, composition, technical capabilities, consistency etc. These factors go some way to describe a well-designed GUI. However, Galitz et al., argue that GUIs could be judged more pragmatically and reduced to a much simpler guide i.e. 1) what we see, 2) what we need, 3) how we think. (Galitz.W, 2002) Alternative means of reading a GUI/ web page for a NS, VI individuals would be:

- an audio file recorded by a sighted individual
- an audio digital screen reader (e.g., Jaws)
- Braille and tactile transcriptions via paper printouts

The common usability **issues** of GUIs for VI people, rather than NS people, are:

- lack of contrasting colors
- insipid trend colors
- heavily layered graphics
- dynamic buttons
- hidden cue points

[10] A GUI relates mainly to a Windows platform Graphical User Interface, often pronounced a Gooey. A GUI is a visually based window with which to view web pages.

- drop boxes or small fonts on alert dialogue boxes

Comparatively speaking a key list of attractions for FS people, is a distraction or the barrier to a person with sight loss. It is clear, therefore, why haptic designers have been inspired to source alternative means to interact with GUIs, which can be driven by other multi-sensory perceptions.

2.7.1 Graphical user interface and sight impairment

Previously researchers such as Mynatt (Mynatt, 1994) and Csapo et al., (Csapo and Wersenvi, 2013) have offered alternative means of interacting with GUI, via audio to supplement sensory engagement for people with sighted disabilities. Csapo et al., offered that their version of Virtual Audio Displays (VADs) could be interpreted as auditory representations derived from human speech, music, and environmental sounds(Csapo and Wersenvi, 2013). In 2009 Wersenvi examined the concept of translating 'emoticons' into non-verbal audio translations to add value to users with sight loss. The outcome of non-verbal emoticon noises was widely accepted and added a level of fun to the sharing communications of emotions. Wersenvi added to this via a single emoticon such as smiling face, with a non-verbal sound equivalent such as the sound of laughter (WERSENYI, 2009)

Mynatt focused on creating an auditory version of the GUI interface which has added interesting input for haptic interfaces. Mynatt recognized the need for a set of principles, one of which was the need for a constant object for recall and memory in GUI interface and recommended this be translated into the audio screen interface. She also noted the need for iconic representation which needed to include color, size and shape of the icon (Mynatt, 1994)

2.7.2 Assistive technology overview

The expectation of AT is that it will increase the quality of life for the user and allow easier access to the everyday task. Many AT devices could be said to meet expectations and they are tenable to meet users' needs. However, as discussed, there are many reasons why ATs fail, and become abandoned leaving the user to seek alternative assistance, usually human assistance, which in some cases, is seen as diminishing the individual's autonomy and independence. The following table outlines examples of ATs, and although this is not an exhaustive list, it does cover most of the important function categories of AT use in the UK.

Table 1 Assistive Technology for people with sight impairment, (adapted) overview of AT categories RNIB.org RNIB, 2016).

Assistive Technology (AT) Category	Brief descriptor and examples
Communication tools	Screen text transcription, speech to text and audio. Examples such as screen readers and voice recorders would be placed in this category and e-Braille aids.
Daily living aids	Tools low and high tech, which aid tasks in everyday life. Examples would include: Braille watches, modified utensils for cooking and eating, easy grip handles, clothing dressing aids – intelligent tagging allows people to autonomously select clothing and dress themselves.
Environmental and travel adaptions	Low and high tech tools which allow users to travel in public buildings, walk unaided by another person. Examples include audio mobile aids, low and high tech tactile maps and canes (sonic and manual).
Vision and Reading Aids	Tools in this category would include any aid which would allow a low sighted individual to read or see text, or to read it via touch. Examples include- magnifying equipment/Braille (manual) which would allow people with some low vision to read for themselves or audio books for people without sight.

2.7.3 Tactile pictures – manual - low fidelity touch AT

A specialist field in NS, VI AT is tactile pictures, the idea being that people with sight loss are trained how to make images through various means of layering or embossing and this enables them to make pictures which can be read by other people with sight loss. There are several ways in which to achieve tactile pictures in low and high tech versions. Kennedy offers the following low fidelity tactile tools for the creation of tactile pictures:

'Applications' *(low tech)*, this is a version of creating a relief picture via layering varied surfaces on to sheet card or paper (similar to collage). This tactile picture can convey a scene or even offer directions as a map.

Emboss and relief *(low tech)* -plastic sheet layered on cardboard or foam surface is pressed by a blunt stylus to create an emboss effect on the sheet that once turned over can be read as either emboss or relief line. This process was favored by Kennedy et al., for use in observing nuances of blind drawing and understanding (Kennedy, 1997).

Kennedy's work has historically investigated specific blind participants who had already shown an interest in recreating 'tracings' of real-world objects and buildings. Kennedy's studies support his participants' ability to translate and draw 2D objects via linear wire objects, or 2D models via raised line drawings. Kennedy's findings showed that people with and without sight share a common shorthand for real-world objects, for example, birds, houses, flowers (Kennedy, 1997). Kennedy also found that by using simple tools such as cardboard, thin plastic sheet and a plastic stylus people with sight loss can trace relief lines in the plastic sheet. Blind subjects were shown to feel the lines, reflect and then adapt their drawings accordingly, thereby showing a sense of edit and redraft according to their needs. Heller, McCarthy and Clarke(Heller et al., 2005) showed that NS individuals can match sighted subjects with accuracy, but better their time when matching symbols. Heller et al., also showed that predictably people who lost their sight later in later life have shown greater understanding of objects and thereby recognized objects faster than people with sight loss in early years but more effectively than the sighted control group.

2.7.4 Tactile pictures, 'mid-fidelity' AT solutions

The digital form of tactile picture/map creation is the 'Picture in a Flash (PIAF) often used for 'wayfinding' usually maps of buildings or short distances. The imagery is created through the use of printed image on specialized paper, the page is passed through a heated base plate, and the heat swells the image where print ink is present. The difficulty with this form of tactile picture comes when the picture is complex or uses fine detail imagery. The more ink present on the paper, the more 'swell' is created in the lines of the picture, thereby the feel of the picture will become too confusing to read with bare fingertips.

Thermoforming *(mid-tech),* this form of tactile image offers a more 3D approach to a picture. Users create a relief image using 3D palm-sized objects, plastic sheet is then put on top and this is placed within a 'vacu-form' machine. The plastic sheet melts under the heat and a 3D tactile image is created for users to read. The coupling of audio and touch has been shown as an aid to translate more complex imagery. Parkes (Parkes 1988) with the NOMAD device offers users a tactile map placed on a touch tablet linked to a PC, the user touches active points of the map with a stylus and an audio message relates the place name and orientation cues.

Mid to low tech AT solutions have allowed people with sight loss, vision impairments (VI) to interpret pictures through touch alone (physical or VR). The addition of audio (dual sensory input) can aid and overcome the complexities or overcrowded maps or pictures. These forms of AT are not without their issues, but simple changes e.g., enlarging and simplifying shapes, have been shown to be useful. Touch led image interpretation of this type has given way to other investigations on how best to facilitate digital dual sense interactions pictures, maps, graphs and charts to aid a individuals without sight.

2.7.5 The Arts and assistive technology

Due to the vision-centric nature of most art practices e.g. painting, printing, and drawing NS, VI people have found it difficult to become involved with these practices on any professional level. For NS, VI it is also difficult to 'view' other artists' works presented in a gallery context, or museum setting. Added to this, museums and art galleries regularly display valuable artifacts open to the public, but use a 'Do Not Touch' sign. Generally the 'Do Not Touch' policy is linked to insurance issues and the potential damage of highly prized pieces. That said, more recently museums and galleries have become aware of the visual-centric nature of the exhibits and how this could impact NS, VI visitors. Therefore, 'analog' touch-led artifacts have been made available to support a NS, VI 'audience'. Although this addition seems to solve the issue, it is a short-term fix. In the longer term, the physical space in museums is limited and so these traveling exhibits do not exist long enough for NS visitors to fully utilize the facility. Museums, with the aid of haptic research communities [42], have explored the added value of virtual haptics to enable users to attain more consistent 'hands-on' interaction. This work, although still in development stages, has the potential to offer new paradigms for increased accessibility to museum visitors.

2.8 Haptic assistive technology

To further consider NS, VI community MH needs, Pawluk and Kitada (Pawluk.D, 2015) inform that haptic Designers/researchers need to consider the following key elements: user characteristics, the level of user involvement in the design process, behavioral analysis of user, some example insights from behavioral research that were applied to the design of assistive technology; insights of previous studies, and some examples of current commercial AT that has been developed for key tasks. With Pawluk et al., key elements in mind the following subsections will provide an overview of current state of the art review of haptic-based AT solutions. This section does not attempt to offer a complete audit of haptic VR applications. Instead it offers a selected sample of haptic AT categorized as the most relevant haptics applications for NS, VI users.

2.8.1 'Talking point', concept design and assistive technology

Yanko Design (Yanko, 2018a), is a design E-Zine[11], which features Designers who have been inspired by inclusive design principles. However, some of the Yanko Design products appear to not consider "form beyond function", but rather "form over function"(Schofield.J., 2008). Yanko Design products are concept-driven, rather than user-led or based on firm inclusive design models. Philip Stark, a controversial Designer who designed the much-maligned concept product the 'Juicy Salif'®, the juicer which was in fact incapable of juicing fruit. Instead the Juicy Salif® held the status of a retrospective style form and was thought to have elevated the object from the mundane and every day. Stark is rumored to have said: "It's not meant to squeeze lemons, it is meant to start conversations." (Watson-Smith, 2010).

[11] An E-Zine, is an electronic Magazine, it is common for design or style media companies to use web based magazines to increase interaction and debate.

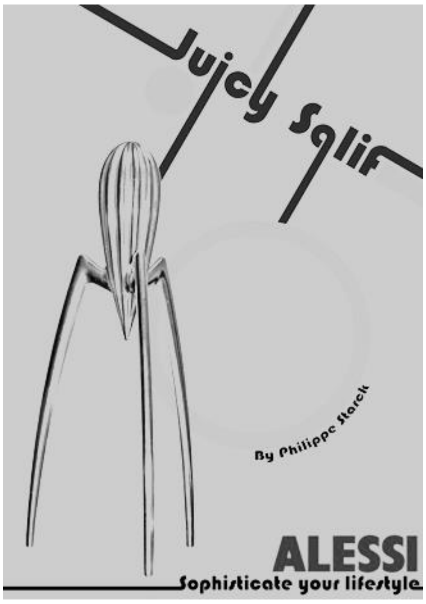


Figure 7 Starck.P 'Juicy Salif' source Alessi.com

Examining critical reviews on some of Yanko Design products, there is a consensus that the AT products address styling issues, and offer concept discussion points to a wider design audiences. The Haptic Braille Mouse designed by Baek Kil Hyun(Yanko, 2018b), in response to Samsung Art and Design competition, hints at the notion of an ergonomically designed shape but lacks user-led efficiency. Shaped like a PC-Mouse the Haptic Braille Mouse was designed to be moved horizontally across printed book text, allowing the NS,VI user to feel raised rubber Braille dots through the surface of the handheld device.

Figure 8 Yanko Design Haptic Braille Mouse

The challenge to the efficiency of the Haptic Braille Mouse, is that the width of the mouse only allows small sections of Braille to be scanned and revealed to the user, which makes the use of the device rather time-consuming. Jack Schofield's (Schofield.J., 2008) article in the Guardian (online) entitled '*Yanko Design: Wow that's amazing! What's it for*?' he questions whether Yanko Design products are usable, useful, or just show-casing shape and style over substance? Whilst politically it would never be appropriate to endorse that AT design should be centered on shape and style, it is the author's opinion that showcasing this type of product as a 'design concept' supports the discussion about raising the quality and usability and disseminates new ways to consider inclusive design by challenging the aesthetic and ergonomics of current AT. However, this type of style without function could never sustain the title of universal or inclusive designed products, and if not challenged by users could become another number in the abandoned AT list.

2.8.2 Wayfinding

Wayfinding can be a real-world, as well as, a virtual world, application. The real-world applications are usually body mounted or handheld haptic devices, designed to guide users beyond the limits of users' gait with a cane. Bowman et al., have defined 'wayfinding' as the cognitive process of defining a path through an environment while using and acquiring spatial knowledge helped by sensory cues. (Bowman et al., 2004) Both real and virtual environments are reviewed in this section.

2.8.3 Wayfinding shoes and bracelets

Kammoun, Bouhani and Jemni (Kammoun et al., 2015) created a VI 'wayfinding sole' for the individual's shoe. The sole is designed to offer five different types of vibration (cutaneous) feedback. Three of the sensors are embedded in front- middle of the shoe and two at the back of the sole. Kammoun et al., proposed the wayfinding sole solution to enable VI people who have issues of walking safely and independently. Although the test by Kammoun was carried out with a low number of blindfolded (sighted) individuals, it did navigate the experimenter accurately and it does open the door to more investigations to vibration led navigation as a way to discreetly guide a blind/VI user.

C.S Nam et al., (Nam et al., 2015) trialed a wayfinding virtual realm (VR) experiment using a Novint Falcon haptic device. The experiment aimed at testing NS, VI users' ability to understand object navigation within a VR environment. Starting at the bottom left corner, users were given home cues and expected to navigate diagonally across the virtual space. The virtual navigation was offered in three different conditions, two types of layout symmetrical and non-symmetrical, and two types of density of cluttering with n= 4, 8, 27 virtual objects.

The findings from Nam's study showed that with each condition NS, VI users' used short and long pauses to understand and process their positioning in virtual space before their next move. It was also shown that the cluttered space with n=27 object conditions resulted in greater navigation and fewer long pauses, compared to the lesser cluttered spaces n=4 object condition. Typically, NS, VI users found symmetrical conditions easier to navigate than non-symmetrical. For VI users rather than NS the symmetrical conditions were found to be easier to navigate. NS, VI users overall showed better performances on spaces with more objects in and tighter spaces, offering that a small margin for navigation aids the NS, VI user. And larger spaces with fewer objects do not offer enough tactile friction to guide direction.

Sarang Sheth a Yanko Design featured new designer, developed a body worn haptic device; the device known as 'Maptic'(YankoDesign., 2017), connects maps and haptics in one device. The 'Maptic' was designed in two parts, a bracelet and necklace. The two pieces are designed to feed into the users' mobile phone, which would use satellite technology to locate the user and navigate the user through the haptic jewelry; the necklace is used to alert users against obstacles, the bracelet indicates right and left. Although the Maptic is discreet, it would appear that there could be a lengthy adjustment period for the user to become accustomed to the series of haptic vibrations and buzzer alerts. Once again, the Maptic opens the creative discussion of creating discreet and styled assistive technology, but with the many potential user-led issues the Maptic use is questionable.

Figure 9 Yanko Design Body Adorned Jewellery

Chapter 2 has examined various aspects relating to the present study. This chapter has shown that positive advances have been made in Designers considering ‘user’ with varied needs and developing mainstream design products and services within a universal design framework. A picture of living as a NS, VI individual is presented to offer the reader more of an insight into how members of the sight loss community cope day to day, and how ATs affect/support their interactions with common daily activities. The chapter went on to present a synoptic view of the state-of-the-art of AT, specifically linked to the sight loss community. There was a sharp focus within this chapter on AT abandonment and how to avoid this issue by using more inclusive design principles and elucidated at the option of AT hacking as a way to restart the user centered discussion within AT design communities. In the final sections a review of AT low/mid-range fidelity was discussed along with current haptic AT solutions, with accompanying critical review centered on discourse around ‘form over function’ and ‘talking point’ design concepts which could energize discussions for future AT design.

This chapter was designed to work with Chapter 3, and together it is hoped they have presented literature with the intention of underpinning the rationale behind the need for the creation of Case Study 1 and 2 (CS1 and 2). The next chapter (Chapter 3) defines the workings and use of human touch perception and sensory system together with a shortened audit of MH applications.

3 Haptics (human and machine)

This chapter is the second of two literature review chapters in this thesis. The first half of the chapter discusses relevant factors of the 'human haptic' system. Human haptic to inform on the variety of touch and tactile perceptions that the human hand and skin are able to communicate. The second half of this chapter discusses haptics used to augment touch sensations to the body, but commonly the hand. Two main forms of haptics technology will be mentioned in this chapter (cutaneous and kinaesthetic), but most of the literature is aligned to kinaesthetic haptics, which has been used in the experiments in the thesis. The haptic literature is presented in three parts: 1) Human and Machine haptics, 2) Haptics and creativity, Haptics and sight loss

All of the literature reviewed in this chapter and chapter 2 will culminate in providing a literature framework to add greater understanding to the empirical work in chapters 5 and 6.

3.1 The categories of human and machine haptics

Saddick et al.,(Saddik.EL, 2011) state that there are commonly four categories of mechanical haptics:

1. **Human haptic** – human physiological interaction with the real world
2. **Machine haptics** – human interaction with the virtual world via augmented touch
3. **Computer haptics** – Concerned with developing algorithms to render 3D virtual objects and shapes haptically
4. **Multimedia haptics** – developing the visual and audio haptic sensory interactions within a virtual environment

3.2 Anatomy of the human hand and human haptics

Although human haptics covers the body and the hand. Here we begin with the human hand to reveal its complexity of anatomy but the simplicity of its role - to touch, to evaluate objects and their properties within the real world. The hand, palm and digits are all essential in the processing of passive or active touch activities.

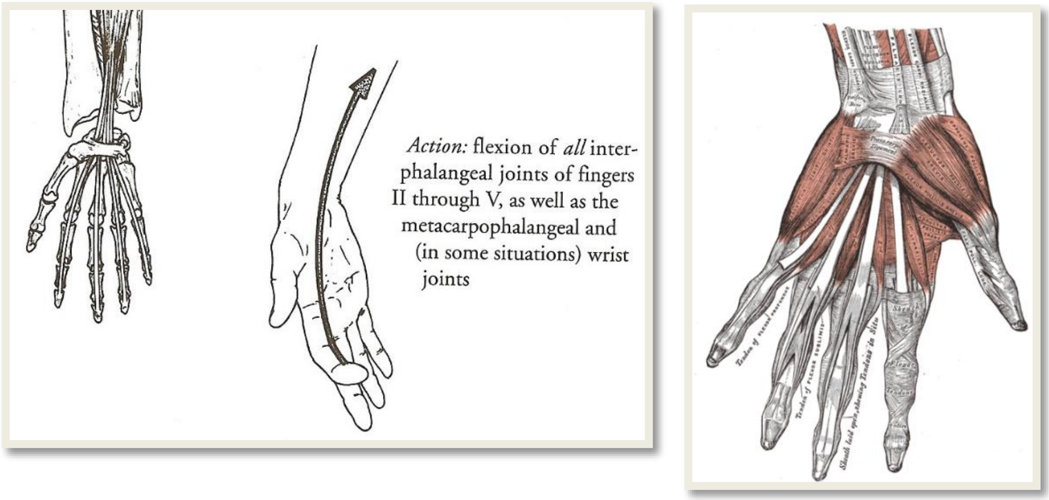


Figure 10 Anatomy of the hand Source: Wikimedia.com (Gray's Anatomy fig. Nos. 426)

The complexity of the human hand is clear when we see that in just one there are up of 29 large and small bones, 123 ligaments and 34 muscles. It is easy to take human haptics for granted, although without it we would not be able to interact and complete everyday tasks. Through the hand humans can grasp, grip, feel temperature, pain and interact and perceive the world around us. But more than this human touch can reassure, comfort others.

Through bi-manual interactions humans use combinations of passive and active touch to conduct object manipulation, and establish usable object properties, on-the-fly. Mandayam, Srinivasan, Biggs, Liu, Schloerb, and Zhou (Mandayam et al., 2005) state that it is essential, in the field of haptics, to gather the basic science of understanding human haptics to support the setting up of the specifications for the performance of haptic machines and provide answers to the research questions.

The following show diagrammatic cross-sections of the mechanics pertaining to the two known forms of human haptics cutaneous and kinesthetic:

- Cutaneous: offers sensory feedback from the skin and the nervous system beneath the skin, cutaneous sensory input could offer pain (nociceptions), contact, or hot or cold sensations.

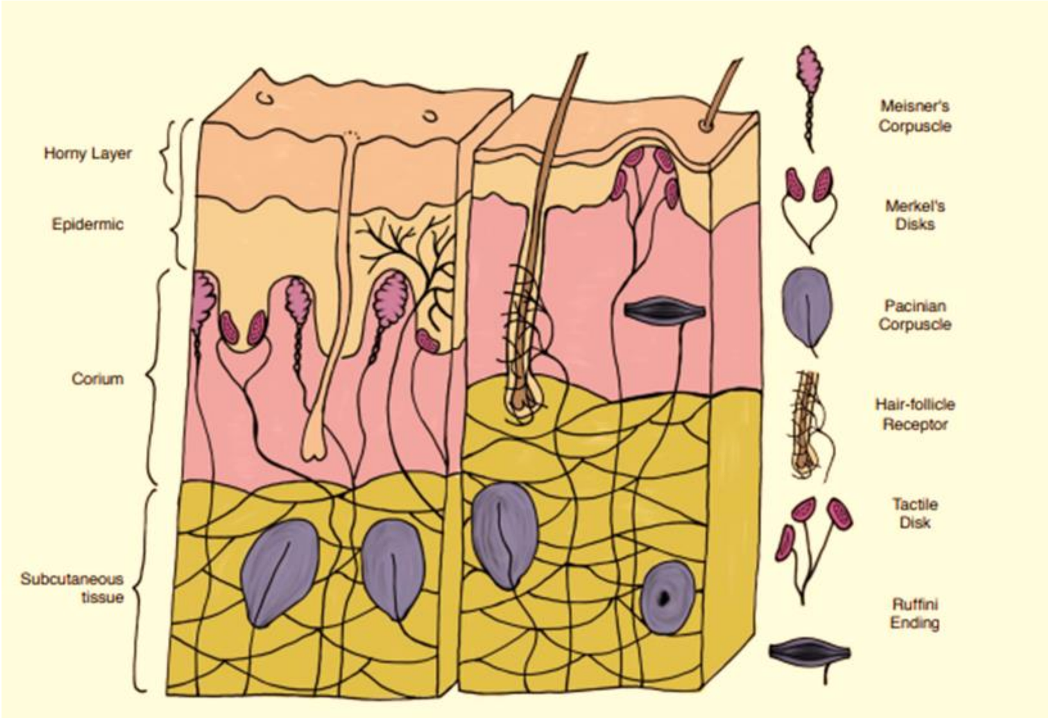


Figure 11 Diagram of the cross section of human skin G. Burdea, “Force and Touch Feedback for Virtual Reality”, 1996

Kinesthetic: offers a perception of body movement or a static location of limbs via receptors in the muscles and joints. Kinesthetic perception could offer grasping of objects with both hands via digits, reaching, activities where the body or limbs are actively moving.

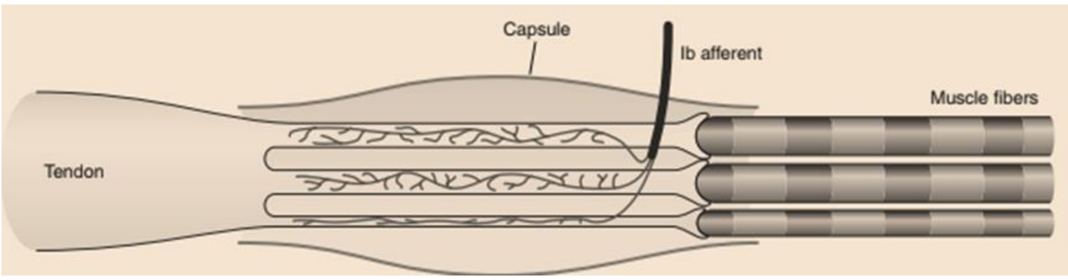


Figure 12 Proske and Gandevia [62] illustration of the Golgi tendon for kinesthesia.

3.2.1 Human haptic sensory system

Robles-De-La-Torre (Robles-De-La-Torre.G., 2006) poses the question ‘What would be worse, losing your sight or losing your sense of touch?’ Most laypeople will immediately select sight loss as being the worst sensory loss, as often it is considered to be more prized in society than touch. In his 2006 paper Robles-De-La-Torre argues that humans actually use touch more than sight, using a well-known patient case study as an exemplar Robles-De-Torre presents a patient who had lost all form of sensory perception. From a place of zero sensory perception, it is then perhaps conceivable that Robles-De-Torre could then map onto this patients somatosensory system the system of a healthy person to compare and contrast somatosensory system and the nuances of touch.

Saddik.EL,Orozc,,A, Mauricio, Eid,M, and Cha,J (Saddik.EL, 2011)discuss the values of touch added to other sensory receptors in the body “… a combination of two or more modalities can be used to characterize sensations such as roughness, wetness, and vibration. A human would not be able to sense and respond to the physical environment without these tactile receptors located over the entire body.” However, Saddik et al, also note that computer scientists have paid greater attention to sight and sound leading to the development of multimedia experiences. Until recent years touch (haptics) has not been seen as a viable way to interact with objects, or data, on-screen.

Often, without conscious thought, we use our hands to explore objects via both cutaneous and kinesthetic modes interchangeably. For example, imagine the simple act of reaching out to pick up a warm cup of coffee, the arm would reach out to the table where the coffee is placed (kinesthetic), the hand would naturally span and then close to grip the cup (kinesthetic), this enables you to feel the warmth of the coffee through the cup and the textural surface of the cup (cutaneous). The arm would then bend and lift the cup, feeling the weight of the cup, to the mouth feeling the warmth on the lip (kinesthetic/cutaneous). Finally we place the cup back on the table (kinesthetic). Obviously, most people wouldn’t break down the isolated haptic modes in an everyday act, such as using a coffee mug, but this small example serves as a way to highlight our sense of touch and highlights how our body’s touch system can offer varied feedbacks from just one manual task.

3.2.2 Muscle and joint sensations (Kinesthesia)

Between the years of 1867-1950 it was debated whether kinesthetic sense (limb motion) was somehow driven by sight (Helmholtz, 1878). In 1900-1950 it was asserted that the muscles and tendons, in fact, had their own sensory receptors, which fed information to the brain to further understand the limb orientation in relation to the body. Sheridan (Sheridan.T.B, 1961) discusses the force control similarities between human and robotic limbs, he presents human and machine of volume to pressure impedance , showing *F* divided by velocity *V*, characterized by Newton's linear dynamical relation in terms of the properties mass *M*, friction *B* and stiffness *K* of the body being moved, i.e., in LaPlace notation .

$$\frac{F(s)}{V(s)} = Ms + B + \frac{K}{s}.$$

Figure 13 Newton's Linear directional Motion in LaPlace notation (Sheridan.T.B, 1961)

Newton's linear directional formula can be used to describe how humans can control their limb position in space and stop or start their muscle control at will, a kinaesthetic robot arm can mimic a human arm in that it can be programmed to change position, and hold its position in space. Kinaesthetic haptics are often used to replace a limitation in some people, for example a limited to the level movement or fine motor skills due to a condition or illness.

A healthy human body is able to move limbs in space and acknowledge where there limbs are in relation to the body. Proske and Gandevia (Proske and Gandevia, 2012) state that the action of moving limbs without needing to consciously recognize the act is due to the proprioception system. Receptors involved in proprioception are located in skin, muscles, and joints. Information about limb position and movement is not generated by individual receptors, but by populations of afferents. Afferent signals generated during a movement are processed to code for endpoint position of a limb. Proske et al., offer the two schools of thought regarding the control of the proprioception sense, one that it is entirely controlled by the brain (Proske.U., 2012), whereas the other asserts that each muscle can hold the information in reception independently (Proske.U., 2012). Bastian(Bastian, 1888) (who initiated the term kinesthesia) believes it is a fusion of brain and muscle reception which allows the movement and understanding of limb positioning. Proske and Gandevia (Proske.U., 2012) advise it could be considered that kinaesthetic information comes from the muscle spindles as shown by the findings which show recordings of second-order neurons which link directly to the pathway leading to the muscle spindles.

3.3 Active touch perception

The active touch perception involves dynamic explorations of an object or an environment. To contextualize this, imagine feeling for a light switch in the dark: you may not be able to see the switch but your sense of cutaneous and kinaesthetic touch perceptions would allow you to dynamically feel around the wall searching for the switch without sight.

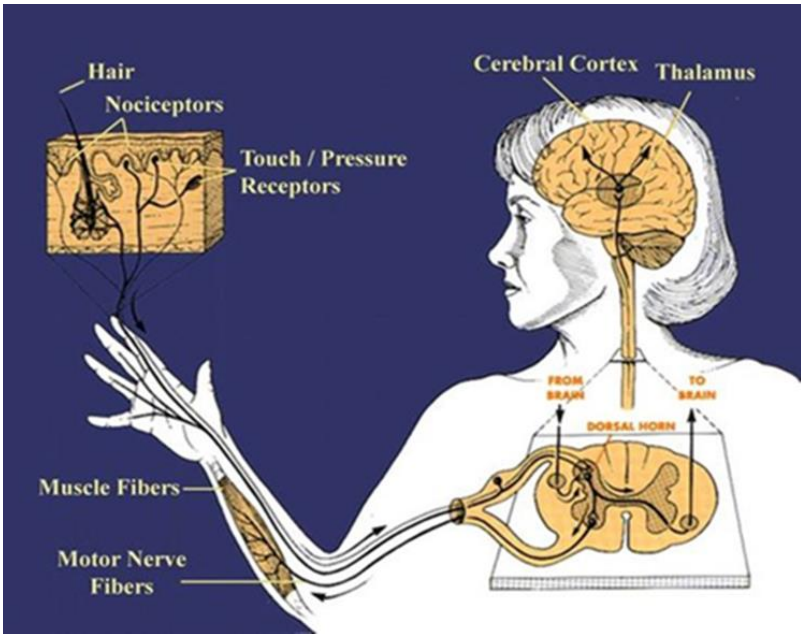


Figure 14 Diagram of how touch pressures and pain are perceived in the brain, inclusive of a cross-section diagram of the receptors in the skin source: Zimmer 2009.

It is well known that sight is seen as the primary sense in the body and often considered the lead sense on many interactions. However, it has also been acknowledged that people do not often need to view an object to use it; working from the previous coffee cup scenario, often one would not look at the object (cup) on the table before reaching for it, as it is often a passive act. This can also be observed when a person is searching for an object in a pocket or bag, the individual would manage to find the object without looking in most cases. Lederman and Klatzky state:

> "People often interact with and manipulate an object without looking at it; to do this, they must know what the object is. When we dress, we do not have to fixate on buttons to fasten them; we can find the button and buttonhole by touch". (Klatzky and Lederman, 2000)

Lederman and Klatzky show in a previous paper (Klatzky, 1985) that 100 familiar objects were recognized via touch alone and within a time mode of 2 secs or less. Lederman and Klatzky summarized the way in which we can assess and name an object through touch alone which has shared elements with memory and sight. To evaluate the nature of the object, it was noted that touch perception relied heavily on texture and the materials of the object, using the memory of the object materials allowing subjects to evaluate the use of the object quite rapidly (Klatzky and Lederman, 2000, Lederman and Klatzky, 2003).

Turvey concurs with this notion and he states,

> "People can perceive a number of spatial and other properties of objects, without the benefit of vision, simply by wielding and hefting the objects."(Turvey, 1996)

The most widely recognized exploratory perceptions (EPs) were defined by Lederman and Klatzky (Klatzky and Lederman, 2000) in their depictions of 'exploratory procedures' from the properties of an object. Lederman and Klatzky investigated touch long before touch was seen as a psychological topic for discussion. The most commonly cited of their work was a series of experiments in which they expressed how participants explore common objects using set patterns of EPs. Subjects were asked to handle a series of objects without being able to see the object or their own hands. Participants were recorded handling single common objects, and the results showed although the different subjects had no knowledge of exactly how they were exploring the given objects, most of them followed a set pattern of exploratory procedures and this was seen throughout the group. Lederman and Klatzky's work also found that when a person wishes to explore certain properties of an object they use particular forms of touch and contact with the object, *(see Table 3).*

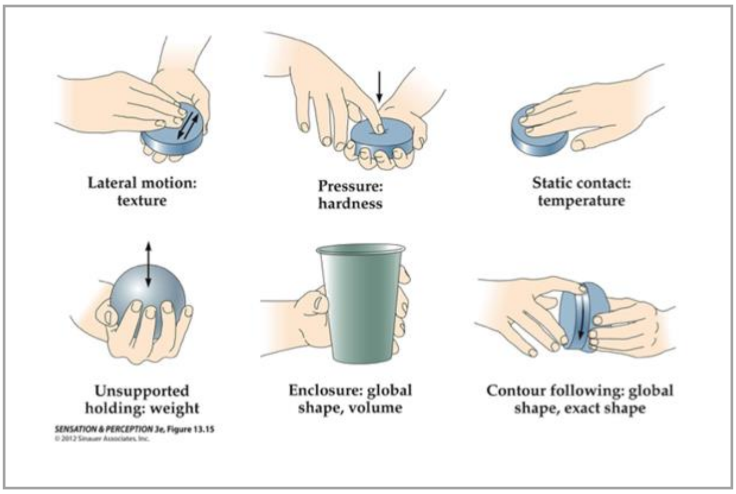


Figure 15 Exploratory Procedures(EPs) by Lederman and Klatzky
(Lederman.S.J, 2009)

Table 2 Lederman's and Klatzky's Principles of Exploratory Procedures[EPs] (Lederman.S.J, 2009)

Contact	Associated exploratory procedures
Lateral movement	Associated with texture encoding
Static Contact	Associated with encoding of volume and shape
Pressure	Associated with encoding of compliance force
Unsupported holding	Associated with encoding weight
Contour following	Associated with encoding of precise contour

Through their seminal works Lederman and Klatzky revealed that the human touch system is a fully cognitive system, playing a role in the direction of attention and providing a substrate for conscious and implicit memory (Lederman and Klatzky, 2003). The tactile properties of an object can be kept in the memory and used against the same object when examined a second time, thereby making future explorations more expedient.

3.3.1 Tactile scanning (aka touching)

Active touch, in the body, works via dynamic contact with an object sometimes called tactile scanning (Gibson, 1962), and is often presented as a mixture of touch feedbacks for example, texture, force/pressure and temperature feedback. Often these sensory feedbacks overlap for example, texture and the temperature of materials. This form of touch is often used by NS individuals to ascertain surface or object information at speed, many link this form of touch with Braille readers.

Millar (Millar, 1994) recognized that any act of movement near an object has an effect on the haptic system. Millar also recognized the use of cross-modal perception, and suggests that the information from one sense modality (touch) can be passed to another (vision) for further recognition and analysis of the stimulus. Ittyerah (Ittyerah.M., 2013) explains that haptic exploration of an object is efficient when examined in a systematic approach rather than an ad hoc tactile approach. Ittyerah justifies how the body angle is a consideration for accurate recognition of an object for blind participants (Ittyerah.M., 2017). In their study of blind participants, Millar and Al-Attar (Millar and Al-Attar, 2003) found that accurately centering the body position aligned to the desktop, aided the outcome of the tactile task allowing for better object recognition, than when the participant's body was at an angle to the desktop.

Gibson's, now classic, 1962 'Cookie Cutter' tactile study (Gibson, 1962), highlighted the positive results gained from active touch versus passive touch. Gibson's active touch study used six cookie cutters (2.5cm diameter) which were pressed into the palm of participants to allow recognition of the edges of the shape and thereby recognize shape itself. Comparing passive and active touch via three conditions, Gibson found that active touch was superior to passive and fingertip searching was more effective than pressing the shape on to the palm. Some of the later touch-based researchers have questioned some parts of Gibson's 1962 'Cookie Cutter' paper. Loomis and Lederman(Loomis and Lederman, 1986) considered whether all of the active touch benefits were down to participants given the opportunity to control their active touch or down to the sensitivity in the fingertips. Wagner(Wagner, 2016) in his 2016 paper questioned the background review to Gibson's paper, especially Gibson's claim that active touch had not been researched in any detail prior to

1962. Wagner goes on to discuss varied psychophysics works, ranging as far back as 1880, where active touch was considered in a novel way via fingertip scanning of stimulus.

Active touch has been cited as a common skill amongst NS, VI people, particularly in the tactile interactions of raised line drawings[12]. Several researchers, in the field of physiological studies, have examined the usability of raised line drawings and how NS individuals 'read' the image through active touch(Kennedy, 1997, Heller, 2005, D'Angiulli, 2011). The issue for NS people is not in the perception of 2D line raised drawings, but in the perception of 3D shapes. The spatial understanding and the depth of plane of the shape in third dimensions often confuses mental images. Picard, Albaret, and Mazella (Picard et al., 2014) emphasized the importance of raised line touch pictures for NS individuals, particularly to gain a better understanding of the image and retain it to memory. Picard et al., indicate the use of haptic semantic cueing (audio), with the aim of improving understanding of raised line images for VI children and a blindfolded, FS, control group(Picard.D., 2014). The study results showed greater accuracy of identification and speed of identification of VI over blind-folded, FS group. That said, interestingly there were commonalities between the groups including the ranking of the difficulty of identification. Although the results showed that VI children had shown better performances, it was asserted by Picard et al., that the study had not shown an examination of 'haptic only' without the audio cues, and this should be considered for future work.

3.4 Machine Haptics and haptic terminology

Machine haptic devices extend human touch perceptions into the virtual realm (VR). El Saddik, Abdulmotaleb, Orozco, Mauricio, Mohamad and Jongeun state that,

> "In general, haptic interfaces have two basic functions; first, they measure the poses (positions and/or orientations) and/or contact forces of any part of the human body, and second, they display

[12] Raised line drawings are simple line drawings, using a plastic medium, the lines are drawn and felt in relief on the backside of the medium.

the computed reaction touch to a haptic scene that populates touchable virtual objects with haptic properties such as stiffness, roughness, friction, etc."(Saddik.EL, 2011)

The division of haptic force could be defined as either force-feedback devices or tactile (cutaneous) devices. As previously stated the preference, in this research programme, is to use the kinesthetic force-feedback device. This is due to the similarities of the device to hands-on kinesthetic guidance, in that as previously stated NS individuals are often physically guided by human assistants to assist their orientation and navigation within their environment. The single point probe of the Geomagic Touch device was specifically selected for the study as it is not dissimilar to the graphics stylus used within the design industry for graphical design work. VI designers and design students would be accustomed to using the singular directional stylus as a design tool to engage with graphics on-screen, alongside the computer mouse.

3.4.1 Bi-directional force

Machine haptics can afford users bi-directional force, akin to human directional interaction, a MH user can apply pressure to a virtual object and the object will feedback a responding force. Prior to MH, simpler forms of singular directional interaction were used to interact with objects on screen, for example, PC mouse, keyboard, or graphics stylus. The graphics stylus could afford the user a slight feeling of drag or pull, but it can only work on 2D planes otherwise termed as '2D graphics'. The standard graphics stylus cannot operate in the 3rd dimension without some form of haptic feedback attached.

3.4.2 Haptic terminology

- *Force feedback - A force simulation provided in the virtual world and felt in the real world. A force could allow a user to feel weight or force resistance against the hand.*

- *Multimodal - A mode is a term used in many different disciplines. In human-computer interaction (HCI) mode is a form of communication of digital data to a human user for example. visual, audio. Multimodal refers to multiple forms of communication.*

- *Haptic perception - (HP) is the process of recognizing objects through touch. It involves a combination of somatosensory perception of patterns on the skin surface (e.g., edges, curvature, and texture) and proprioception of hand position and conformation. (staff.uob.edu.bh/files/600435156_files/MCM250_Haptic_Perception.pdf)*

- *Kinesthetic sense - the sensation of muscle contraction; awareness of movement or activity in muscles or joints; sense of position or movement mediated largely by the posterior columns. (found in http://medical-dictionary.thefreedictionary.com/kinesthetic+sense)*

- *Virtual environment - A digitized space which simulates objects or environments in the real world. The virtual environment can be interactive and immersive.*

- *Immersive - A virtual environment which creates multimodal forms of interaction so the user feels entirely involved with the scene or exploration.*

- *Proprioceptive - Relating to sensory information about the state of the body (including cutaneous, kinesthetic, and vestibular sensations). (Oakley et al., 2002)*

- *Rendering (haptic) - refers to the translation between the computed interaction model (which might be, for example, a static or dynamic collection of virtual objects to be encountered with an actuated probe) and the command sent to the actuated device.(MacLean, 2008)*

- *Vestibular- Pertaining to the perception of head position, acceleration, and deceleration. (Oakley et al., 2002)*

- *Tactile - Pertaining to sense of touch, but more specifically the sensation of touch surface feel, or surface properties. (Saddik.EL, 2011)*

3.4.3 Human-computer Interaction

The value and functionality of HCI systems are that they close the gap between the physical user and digital machine functionality. For the purposes of this thesis study, basic HCI principles were reviewed to enhance inclusive and usability methods. It could be said that, a human designing an interface for other humans should be the easiest brief possible. Of course, it is not that easy as every person has their own set of historical and physical needs, their own history of cultural, social and even political beliefs. A user can also hold their own set of academic understanding, reasoning, aesthetical demands, abilities and expectations of the technical interface. For example, many NS, VI users may not have had the opportunities to use ICT through their early education years. Therefore as adults as they have not been given enough chances to use what digital skills they may hold due to the limitations to access GUI and technology. That said, more recently many researchers/Designers are becoming more involved in creating user-led technologies and devices which offer more access to disabled PC users.

Human-computer interactions (HCI) designers need to take into account a number of guidelines and even legalities surrounding the design delivery and user access to technology and interfaces. Many of the guidelines are often too generic, or even ambiguous, and hence designers need to develop more specific user-led guidelines, based on physical user responses.

David Benyon (Benyon, 2005) offers one such framework to support the design of Human-Computer Interactive systems/devices - PACT framework :

P A C T Framework: People, Activities, Context and Technologies

Each letter of the PACT framework enables the designer to build a picture of the (user) persona, activities required to test the digital system, context of the HCI system, and the technologies required to complete the project. The next stage, in line with design protocols, is the development of HCI. To revert back to PACT, each section of the framework can be broken down to develop it further. PACT begins with people, beginning with user understanding, their understanding of the system and the designers' understanding of user. To investigate user understanding designers often undertake varied levels of observation and recording user activities eye tracking etc., qualitative evidence can encapsulate user needs and evaluate user understanding of the digital system. Evaluations from user are crucial; designers need to be agile enough to consider user evaluations and what this could mean to the next phase of concept design or proof of concept.

3.4.4 Haptic rendered interface

Massie, in his thesis, states that "Visual and auditory feedback alone cannot enable a person to interact with a computer as naturally as he would interact with his natural environment." (Massie.T, 1993) Massie goes on to offer the benefits of being able "to reach through 'the Looking-Glass' of existing computer monitors, and actually touch virtual objects represented in the computer."(Massie.T, 1993) Since Massie's early work, users have been enabled to interact with a haptic rendered interface which enables them to perceive bi-directional force feedback from 3D graphical objects. Many users, using haptic rendered interfaces would now find it difficult to distinguish the haptic force pressures from real pressures, and the mimic auditory feedback from real-world sounds, as haptic rendering has become so sophisticated and realistic. Massie states that a lot of what we do with our hands allows us to confirm what we see, to remember the interaction and to establish cognitive models from what we interact with (Massie.T, 1993). These points could be said to be some of the reasons why applied educational and training programs are now including haptic rendered interfaces and devices.

3.4.5 Haptic (machine) limitations

MacLean(MacLean.K.E, 2008) asks, "What stands between current haptic simulations and passing the haptic Turing test—that is, attaining the ideal state at which the user is unable to distinguish the feel of real versus rendered objects?" She suggests that haptic devices reach this criterion in isolated cases. If the haptic device is utilized for its purpose i.e. GeoMagic Touch™ device (single-point device), used to trace curves and sculpt shapes, then the haptic Turing test could be said to be close to achievable. However, if a user wishes to use one form of haptic device for multiple tasks, close to what the human hand can achieve, then currently this is not achievable. To aid a truer fidelity of touch haptic designers must first decide which user would use the device followed by what form of touch they require and select the haptic device accordingly. The following table outlines some of the limitations for current haptic devices.

Table 3 MacLean's haptic limitations descriptors (MacLean.K.E, 2008)

Haptic mode	Issue descriptor	Reasons	Authors
Kinesthetic	Jitter, or instability of 3D rendered model on screen.	Caused by lack of dynamic software range or refresh rate	MacLean, 2008,Choi and Tan, 2002; Colgate and Brown, 1994; Gillespie and Cutkosky, 1996
	Forces feel 'spongy'	Motors are too weak, updates are too slow	MacLean 2008
	Model feels wrong	Rendering is wrong, the model is unrealistic to capacity of rendering	MacLean 2008.

3.5 Geomagic Touch™ device

As previously discussed the Geomagic Touch™, is the selected device, utilized throughout this study(CS2,3,and4). The motivations for using this device have been mooted above, but on a technical basis the Geomagic's affordance of Six Degrees of Freedom [6DOF] means that it offers the highest form of degrees of freedom of any other off the shelf MH at the time of this research programme. The 6DoF can be broken down into three directions, 1) forward to backward, 2) left to right, 3) up and down, as well as utilizing three rotational axis values of X, Y, Z. Identification of objects using the Geomagic Touch™ feedback can be divided into six haptic-related object characteristics: hardness (elasticity and plasticity) of material, temperature, surface characteristics, shape and size of object, and weight and balance (Sonneveld.MH and Schifferstein, 2008).

Scali, Shillito, and Wright (Scali et al., 2009) are one of the many research groups to use kinesthetic haptic (historically known as the PhanTOM Omni). Scali's study, entitled 'ThinkSpace' presented work with craft-makers. The haptic tool was considered appropriate to the design process due to the bi-directional feedback, the ability to interact with 3D points of a 3D object in virtual space and the ability to include multimodal additions, to widen the sensory engagement, aid user immersion, user navigation and object interaction. The performance measures of the Geomagic Touch device are shown in Table 5 and image of the device figure 17 shows a diagram exemplifying haptic collision detection.

Table 4 Performancemeasures and specifications source: Geomagic website (SYSTEMS, 2017b)

Force feedback workspace	**~6.4 W x 4.8 H x 2.8 D in > 160 W x 120 H x 70 D mm**
Footprint (Physical area device base occupies on desk)	6 5/8 W x 8 D in ~168 W x 203 D mm
Weight (device only)	3 lbs 15 oz
Range of motion	Hand movement pivoting at wrist
Backdrive friction	< 1 oz (0.26 N)
Maximum exertable force at nominal (orthogonal arms) position	0.75 lbf (3.3 N)
Continuous exertable force (24 hrs)	0.2 lbf (0.88 N)
Stiffness	X axis > 7.3 lbs / in (1.26 N / mm) Y axis > 13.4 lbs / in (2.31 N / mm) Z axis > 5.9 lbs / in (1.02 N / mm)
Position sensing [Stylus gimbal]	x, y, z (digital encoders) [Pitch, roll, yaw (± 5% linearity potentiometers

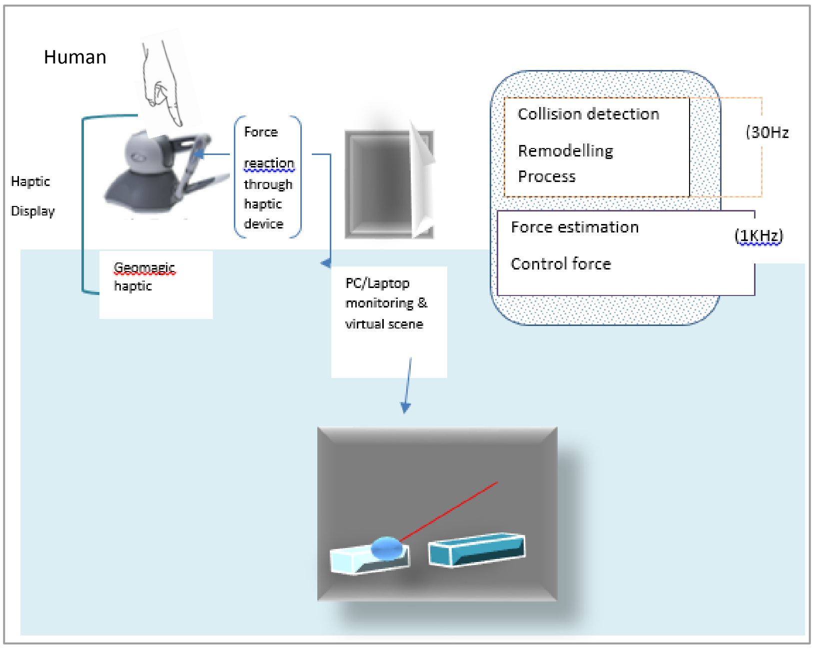


Figure 16 diagram ofhaptic probe dynamically interacting with 3D objects and textural grooves in VE (authors own)

3.5.1 A single-point – kinesthetic force device

The term 'single-point' device refers to the amount of pressure points the user is able to use to control, track and interact with virtual objects. Previously the single-point of connection was facilitated via a thimble end-effector which the user attached to their finger. In more recent years, the thimble progressed to a rigid stylus (sometimes called a probe) with a single end tip. The force feedback is perceived when a user's end effector connects to a plane or 3D shape, once the point in the shape is connected the user will feel a stiffness or a resistance to the 3D object or plane. The single-point haptic device has two contact sensors which measure positioning in VR and translates this to the force required for the user to feel a resistance to a solid object. Force, or torque, are applied through the stylus or probe to the user at a minimum of 1 kHz allowing the user to feel a sense of force resistance, most modern devices provide a range of forces. The movement of the single -point device around a 3D object to identify and trace the object is known as active/dynamic touch interactions.

3.5.2 Application and efficacy of a single-point haptic device

As previously discussed a single -point device uses a single end effector to trace and hold contact with VR objects. It could be said, to some extent, that the limitations of the fidelity of stimulation using single- point device is due to the single point of contact with a virtual object, as in the real world we naturally have five to ten points of contact. However, the limitations of a single-point device can be bridged if the designer exploits the affordances of the tool and uses it for salient actions akin to the users' known touch interactions. In the case of NS, VI people the touch interaction via a linear, tracing action is preferred and utilized readily. For Designers the use of a stylus single-point probe to interact with computer-aided design (CAD) modeling is commonly known and utilized readily. Therefore, this study has selected the single-point probe as the device most commonly linked to both user groups in the study programme.

In order to assess the benefits and impact of the selected haptic device on NS, VI and S design novices, the author felt it would be pertinent to understand the findings of other recognized authors in other fields connected to either the use of single-point for teaching, NS, VI assistance or design process. Many different fields of research and practice have recognized the benefits and potential of virtual 'hands-on' interactions. For MH interactions typically a single-point kinesthetic device has been used with various end effector adaptions to refine the single tip for appropriate use for example, *surgical, clinical, rehabilitative, teaching/training, applied disciplines – design, engineering, science and cultural industries. See further reading* (Amirabdollahian, 2011, Minogue, 2006, Shillito et al., 2001, Brewster, 1994, Colwell.C, 1998).

3.6 Haptics and creativity

3.6.1 'Hands-on' arts

The ironically traditional conventions of the arts practice (UK) are known as 'visual arts'; although this could be said to be merely semantics, this title alone can often be misconstrued to think that visual arts are a purely visual based practice. In fact, the researcher would argue that visual arts are often better experienced via multimodal construction techniques and viewed in the same manner. There are many different subcategories of ‘arts’, dependent on the ‘story’ the artist wishes to express. But classically visual/fine arts are connected to 2D graphical, drafted, printed and painterly artifacts.

Sight-impaired individuals also use arts and crafts to express their creativity and can use arts for its therapeutic value. Touch can allow humans to become immersed in the creative process, that is to say it can offer a feeling of ‘being there’(Sallanas. E-L, 2000). This particular experience was witnessed, by the researcher, from observations collected from CS 1, fieldwork at Henshaws College. In a particular instance, three AM participants were observed to ‘feel’ color. That is to say particular AMs, were considered as skilled painters, and they claimed to be able to feel the tone of the colored paint they were using by feeling the different weights of colored pigment in the paint. During one observation session CS1 AM5 stated, “Do you like the feel of my purple?” (Appendix A). This sensitivity to touch could be said to be related to the AM5 consistent use of dyes and pigments and only being able to use their sense of touch. However, from successional observations and consultations with Henshaws experts it can also be suggested that some AMs held particular sensitivities of tactile sensations and perceptions which aided their process.

To aid AMs interaction with color, varied innovative manual assistive techniques were used. One particular method was to use rubber solution within the colored paint. This allowed AMs to apply a rubber mix medium, with a naked hand or fingertip, through a textured mesh on to varied substrates, often the medium was arranged in some form of pictorial imagery. When dried with warm air, the colored rubber mixture would expand and harden thereby creating a tactile relief line to haptically trace with a naked fingertip or palm. Another technique, for Braille readers’, was to use small pieces of fine grade sandpaper which had primary colors rubbed into the surface. The AMs knew the color ranges were cross-matched to the grade of sandpaper, from this it could be established which color was which just from the feel of the paper. The sandpaper/ color chip method also cross-referenced with the sandpaper label on the paint bottle.

NS art charities such as, Henshaws College [UK], Art beyond Sight [USA], and Blind Arts UK, have all stated that NS participants have been shown to have adept active touch, specifically observed when working with arts/crafts. NS artisans are more adept and predisposed to hands-on applications and construction processes as they hold skilled sensitivities to touch. Touch-led and multimodal interactive arts have been exhibited online or in NS arts' venues across the country. The assistive adaptions to NS artists making the art autonomously in some cases can be as simple as changing the lighting in the environment or working with arts materials in more interactive ways.

The RNIB state,

> "Many artists devise simple, yet ingenious ways of changing their style and adapting their approach to making art after losing their sight. This might involve developing new techniques or using different equipment." (RNIB, 2014-2018)

Whilst touch is important in the process of many arts, within the context of Visual Arts, it can be seen as only producing applied craft work, often viewed as a lower valued form of art. Historically craft was given the stereotype of being 'homespun' and makers were seen to hold lower-quality skill levels. Crafts were purely something housewives did to pass the time. However, in more recent years, the Crafts Council have forged a new level of quality to crafted objects, the label 'handmade' now readily conjures up a quality product without mass-produced manufacturing process.

Figure 17 An example of the process of 'Guiding Hands' from Henshaws College.

Charities such as Henshaws Arts Charity for Blind and Visually Impaired have picked up on the modern value of hand-touch or handmade artefacts and have purposefully used the Crafts title to aid their plight to reconnect society with a unique, skilled product, whilst also enabling NS artisans the opportunity to sell their work and practice their 'hands-on' work. Figure 15, demonstrates the 'guiding hands' of teaching assistants of AMs. This procedure is one of many unique assistive procedures devised by Henshaws' arts staff to aid and guide AMs in their work. Henshaws staff particularly have set manual guidance rulings. For example, rulings specify specific touch points on the AMs body usually the wrist or the crux of the elbow. AMs are usually guided this way when navigating physical studio space as well as navigating artwork. Guiding hands has been shown in practice to aid the AMs mental mapping of their artwork. It also allows recognition of where the artwork needs to be developed further.

3.6.2 Human-computer interaction with 3D computer-aided design (CAD)

Sener and Wormald (Sener.B., 2007) have targeted the rather limited research area of HCI for 3D CAD. Sener et al., reports that there are only two main CAD systems which support concept generation, Free form® 3D Systems- Geomagic Touch(Systems, 2017) *(was Sensable)* and Alias Studio™ Auto Desk (Autocad, 2017). To counter this, and to respond to industry's call for better industrial design concept generation, Sener et al., designed varied contexts for concept generation. Eleven concepts contexts were presented to sixteen UK based participants (experts in Industrial design) for evaluation. Sener et al., were set on providing better-recognized context spaces where designers could be freer to organically draft and draw, something which is completely denied in precision drafting tools such as AutoCAD. The freer concept was met with enthusiasm by industry expert users who willingly endorsed the concept of a more creative freer way into the early stages of design.

Design researchers such as Bordegoni and Cugini and Verplank(Verplank.B., 2003), also touch the edges of this area working towards a more engaging and immersive version of 3D Design HCI which aptly fits the Designer- user. That said, it is clear from this work that to create new visual design mimicry creates a niche concept suited to aesthetical / visual feedback, this work could be contested. Ultimately, virtual multimodal systems should become a tool which any designer, irrespective of ability can pick up and use to create a design product, which can be presented to any client, in a manner which is pertinent to the design brief. In this instance the design interface needs to be universal or adaptable to enable Designers to work with more convincing virtual 3D products.

3.7 Haptics and sight loss

As previously discussed it could be said that the NS, VI community are well placed to exploit the benefits of MH, as they already readily use the sense of touch proactively for object recognition, spatial understanding etc. However, NS, VI communities are a heterogeneous group, the variations of sight acuity and how individual's sight is fully utilized is dependent on a large number of external and physical variables; variables which include less tangible more emotive issues for example, the individual's confidence, the character of the individual, individual learning skills, tactile training or academic ability and/or personal lifestyle habits. Additional factors, such as age of sight loss, have also been shown to affect how an individual is able to perceive the environment e.g., someone who loses their sight later in adult life could be deemed better at depth/spatial perception than someone who lost their sight as an infant.

McGookin and Brewster (McGookin.D., 2006) acknowledged that when there is a lack of multimodal interaction in teaching and learning for NS learners there could be an overload on to a singular or dual sensory input. McGookin and Brewster (McGookin.D., 2006) go on to disseminate haptic empirical testing which include dual audio and graph line haptic rendered interfaces. They worked with NS participants to interpret numerical interconnecting graph line series. Results showed NS participants could advise on the precise location of the intersecting lines on the graph. However, some participants were confused when the haptic and the audio lines crossed and they received simultaneous mixed sensory feedback, which proved difficult to understand. The redeeming points of this system was that NS users could gain some form of mental mapping of the graph lines they were interacting with, which was more informative than audio transcriptions alone.

3.8 Haptics and Education

3.8.1 Human Haptics: teaching and styles of learning

It has been widely disseminated that different people learn via different learning styles. From Kolb's reflective model (1984)(Kolb and Kolb, 1984) to Fleming's VARK theory(Fleming.N.D and Baume, 2006), there have been a number of learning styles identified at particular levels of education throughout our lives. The reflective model was expressed by Bamburger and Schon (Bamberger.J., 1983) but inculcated into Kolb's Learning Cycle. Pedler's version can offer the students a set of reactions and behaviors to learning, and this can be adapted to suit any form of discipline, but as it is based on experiential learning it pertains readily to creative practice and applied studies and as such learning behaviors has been considered as a pertinent part of this study program.

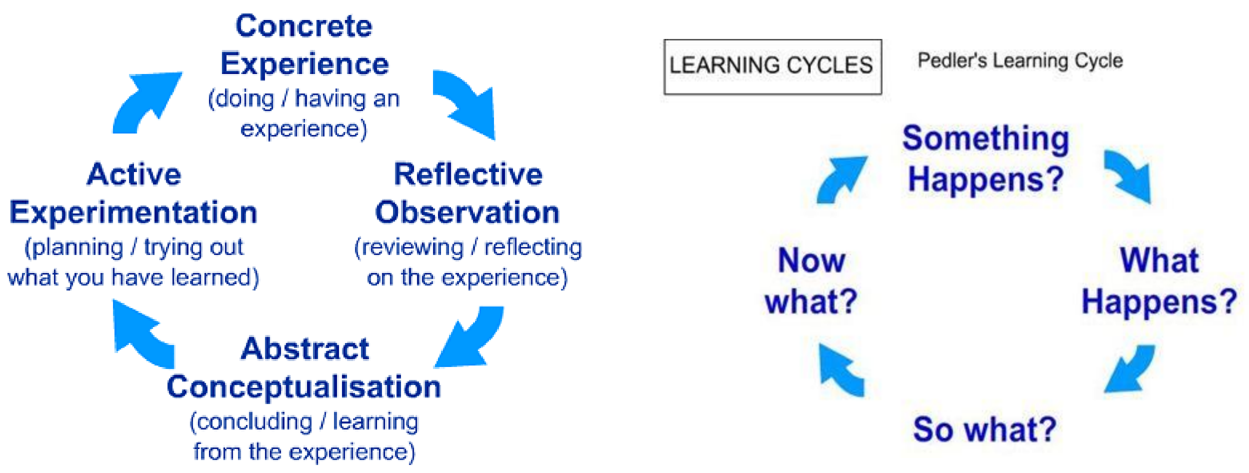


Figure 18 Kolb's Learning Cycle compared to Pedler's et al., Learning Cycle

1. Reflective Observation -of the new experience. Of particular importance are any inconsistencies between experience and understanding.
2. Abstract Conceptualization- reflection gives rise to a new idea, or a modification of an existing abstract concept.
3. Active Experimentation- the learner applies them to the world around them to see what results.

The most recognized labels for the various styles of learning are visual, aural, reading and writing and kinesthetic (VARK). That said, more current thinking shows that our learning styles can change with the age, experience and development of the learner. Learning styles can also change according to the subject being taught. Design and Arts subjects are classically tactile kinesthetically led, historically design process has been shown to be taught in aural, visual, and kinesthetic learning styles. Nowadays, the 'science' of learning styles has been disputed by scientists. The emphasis has now been placed on evidence-based learning perceptions. The work by Newton (Newton.P.M, 2015), does not dispute the fact that learners may learn better through a mixed sensory approach, the 'pigeon-holing' of students' learning style was being brought into question and largely dismissed due to the lack of neurological evidence.

3.8.2 A case for experiential learning and haptics

Minogue and Jones (Minogue, 2006) present a comprehensive review of M and MH used to understand how haptics may affect learning. Minogue et al., examine dual coding theory as part of a cognitive load and learning examination. Paivio states that cognitive progressions can be developed through the use of the Dual code theory advocates that there are two types of information; 1) nonverbal (*imaginary*) and 2) verb (Paivio.A, 1991). Cognitive load can be understood by how the sensory information is shared across the sensory input channels. Minogue at al., inform that haptics may aid teaching and learning a way of 'learning by doing', the idea of practicing the dynamic movements to further understand theoretical concepts (Minogue.J., 2006)

A great deal of recent haptic literature (2000-2017) has reported using a variety of haptic devices to enhance formal training in specific subjects for example, maths, sciences, arts, veterinary and dental training. Using haptic tools can add another dimension to the students learning to offer less transmission style learning (passive) and more active applied learning. Barfield (Barfield, 2009) states "Allowing students to actively touch and explore objects has been shown to aid the process of learning; for example, allowing students to directly manipulate objects may assist the student in overcoming conceptual barriers to difficult science, mathematics, and engineering concepts". Barfield further reports that there are many different applied science and chemistry fields where haptics could 'close the loop' of learning. In engineering, for example, students could be afforded to trial complex mechanical assembly tasks using a haptic device, science students could touch a nano-particle usually too small to be seen by eye, or astronomy students could touch a planet, or examine the surface of the moon (Barfield, 2009).

3.8.3 Technology-enhanced learning

In the twenty-first century the use of technology is a ubiquitous part of our everyday lives. However, embedding technology into teaching and learning is not as simple as merely facilitating students with access to the technology. From the very early stages of teaching and learning, academics need to consider which technology is the most appropriate for the given learning outcomes and assessment needs. Currently, as more learner needs are being considered alongside the learning criteria, more Universities are considering in more depth how accessible the technology they are using is, to all learners' ability needs, and which technology could overcome barriers to learning. JISC statistics:

> "Technology-enhanced learning is modernizing the global higher education market, Student Digital Experience Tracker found that 70% of HE and FE learners agreed digital technology on their course allows them to be more independent in their learning, fitting it into their lives more easily. Furthermore, 82% of HE learners felt digital skills would be important in the workplace, but only 50% agreed their course prepared them for the digital workplace". (JISC, 2017)

As seen previously in this chapter Brewster et al., (Brewster.S.A, 1998, Brewster.S.A., 2004) assert that haptics can help with information overload on one sense or to lessen information clutter. Applied disciplines such as engineering, surgical practice and design/arts practices are well placed to use a touch-led technology to augment a learner's interactions with learning models and materials. Baillie et al., invented the 'haptic cow'(Baillie, 2005), veterinary schools across the world have been using it to offer students explorations of bovine anatomy. Users enter the resin shell of a cow using their bare hand, inside the resin case there is a bovine uterus which is connected to a robotic arm. Students can experience the feeling of what it is to palpitate a cow's uterus using the haptic cow system, the digitized system also allows parallel tutor instruction guiding the students through the system and instructing use.

Haptic training devices can also be used to protect trainees from real-world risk of injury in extreme working environments. This has been shown through the use of haptics for flight simulators and many military simulator systems. It may also protect the risk to others, shown in the use of surgical simulated human body, which allow surgeons to practice intricate surgical procedures before carrying the process across to live patients. A specific case of haptic tooling used to protect trainees is L and T, one of India's largest engineering and Construction Company. L and T employers realized the potential of using haptic tooling to protect employees from harm, but also saving costs of physical training materials and tooling for trainees (early stage). By keeping a battery of haptic rendered forces which mimic materials akin to real world, has meant that L and T can train individuals in real-world processes without the expense and risk to human health. (Ammachilabs, 2018)

Figure 19 Ammachilabsimage of haptics used in LandT, India. (Ammachilabs, 2018)

3.9 Haptics by design

3.9.1 Traditional creative process and haptics

"…how fundamentally important it is for teachers to realize that the nature of creative expression is bound up with haptic perception… this is the artist's basic and habitual mode of experience." (Lowenfield, 1952)

The development of haptic technology has not gone unnoticed within many applied subject areas, inclusive of arts and design. However the arts and design communities hold on to their classical values and feel duty-bound to uphold their manual creative skills. As commercial business moves forward, so does the need to utilize more and more time-saving devices and to communicate across a global network of consumers and manufacturers. There is a pull to go towards technology from some Designers, with some faction within creative groups finding a way to combine manual and digital inclusions, and others ignoring the affordances of any technology as it is believed to deny any creative freedom. This means the volume of research presenting the use of haptics within art/design is scarce and limited in its development of haptics for studio use.

3.9.2 Manual versus technology for concept generation

Since the Bauhaus movement in 1919-1933, the formal teaching of art and design was reassessed. The Bauhaus movement created a platform of processes and procedures which are still practiced today in studios and education facilities around the world. For example, the germinal stage of design process, the development of process and final stages were all established as an outcome. Designer-Makers[13] became empowered to openly communicate their lesser quality 'sketch models' within peer discussion; now referred to as a 'peer crit'[14].

The discussion over manual versus technology amongst designers was heightened around the development of high powered computers and better visual fidelity of 3D objects. The use of CAD took away from laboring on prototype models by hand, but it also created a debate as to whether CAD has diminished the skills of a Designer. Over, the last decade CAD has pervaded many university creative labs, and design studios. The ability to model in 2D/3D via technology and to develop and edit the model in real time is a great advantage in saving time for time-poor designers. CAD software allows instant color change, change form of surface texture 'on the fly'. This kind of affordance is key to why so many designers and design students utilize CAD, as short concept deadlines can mean less time for handmade studio models forcing the designer to use software which can save time and enable the designer to email the design concept globally in minutes after creation. In the last 5 years, CAD systems have increased real-world simulations of surface, structure, so visually a designed virtual model can look as credible as a real-world model. That said, there is some debate in industry

[13] Designer-Makers are people who design and make the artefact without the aid of industrial manufacturing processes; usually Designer-Makers are self-employed small businesses making one off objects.

[14] A peer crit is an industry term to mean a critical discussion amongst colleagues or creative peer.

by classically trained designers who note that currently CAD interactive tools are limited to a PC mouse or keyboard, so that they do not feel as in control of the final prototype concepts. And the use of CAD can be seen, by some clients, to take away a sense of human interaction both by the client within the real world and the Designers who ultimately want to use a fusion of manual modeling and CAD.

Many 'Designer-Makers', as previously noted, are attracted to a sense of a 'truth to materials' and hold an enthusiasm in retaining hand-touch traditions. Designer-Makers would not usually wish to translate their concepts into digital versions. Designer-Makers often utilize their individuality of touch to define their creative signature or 'makers mark', this is a mark or intervention technique which is original to the maker e.g., a potter may use their thumbprint in place of their signature.

3.9.3 'ThinkSpace' haptics by design

Scali, Shillito, and Wright (Scali et al., 2009) via the 'ThinkSpace' project, have analyzed the use of technology as a tool to develop product design at the conceptual stage. Scali et al., acknowledge the struggle between the beginning and the end of design process where there is a dichotomy for designers wishing to stay with traditional sketching and modeling process, but also being driven by the issue that at some stage their design concept needs to become digitized for manufacture. The ThinkSpace project correlates with the author's own views that offering an advanced set of touch interactions (haptic tooling) will allow designers to become more hands-on with virtual making processes. This could result in designers maintaining a consistency of the hands-on process throughout the sketch and modeling processes.

Scali et al., express that:

> It could be hypothesized that VR technology coupled with multi-sensory (e.g. haptic and visual) feedback could provide the best alternative available. Intuitively virtual reality is meant to be the best alternative to reality for "experiencing" 3D space (and therefore shapes in that space)...(Scali et al., 2009).

Bourdot and Touraine (Bourdot and Touraine, 2002) developed a CAD interaction system with added haptic affordances. The study by Bourdot et al., was premised on an industrial layout and offered users the ability to modify objects by adding or taking away shaped forms within a 'CAVE-like' immersive environment. The study used two methodologies, working with gesture haptic feedback. Findings of this study revealed that there was further work to be done on specific elements to review the time taken to examine and extrude models over that of models used in CAD, as this element was protracted because of the use of gesture haptic force feedback.

Cheshire, Evans and Dean (Cheshire et al., 2001) have created a case for haptic technological intervention for craft-based objects, traditionally thought of as artifacts which are purely manually labored and finished. They state:

> “However there is a strong groundswell of opinion that tactile product development is beneficial to the final products form and so a way should be found to combine the craft-based techniques with digital product development”(Cheshire et al., 2001).

Cheshire et al., did find that detailed surface work was credibly created using the dynamic probe to indent on the prototype model, such as hammered effect, although a smoothing effect was difficult to obtain using the FreeForm software alongside the Phantom Sensable (now known as Geomagic Touch). Overall, however, it was found that the single-point device was able to achieve most surface reproductions and tool processing of form and surface as could be found in the manual studio tool use. In summary, Cheshire et al., state:

> “Instead of attempting to adapt established practice into a digital format (e.g., workshop-based form-giving translated to a haptic feedback (device), it may be more appropriate to identify what the industrial designer is attempting to achieve through tactile interaction” (Cheshire et al., 2001)

This is a pertinent observation, as some designers may wish to use the sense of touch to not only define the form and surface of a designed object but they may also wish to utilize the haptic interface to offer surface texture and definition to clients in order to convey more of the product than just the aesthetics.

3.10 Summary

This review of literature has highlighted that although haptic feedback has the potential to support applied creative process there is still some way to go for haptic augmentation to match Karen MacLean's so-called Haptic Chalice(MacLean.K.E, 2008). This means that the haptics becomes so advanced that the user feels that the use of haptics is innate, they feel completely immersed / present in the virtual space they are interacting with. That said, this research shows through works by Brewster(Brewster.S, 2006), (Brewster, 2001) McGookin (McGookin and Brewster, 2006), and Wall (S.A, 2006), that if haptic tooling is carefully aligned to an appropriate task and the user's HCI needs are considered, then haptics has the capacity to afford new innovative touch interactions for a wider audience.

Although art and design disciplines are a relative 'newcomer' to haptic use, the work of Shillito et al.(Shillito.A.M., 2003), is encouraging as they have highlighted how using haptics to mimic real-world design processes is possible; moreover, even the most skeptical designer seemed willing to adapt to the new technology.

This chapter has contributed to the thesis overall by informing on the nature of human and machine haptics, within a user-led framework. Moreover, this chapter has revealed a lexicon of relevant terminology to aid the reader going forward into the next chapters. The next chapters report on the methodologies used to investigate NS, VI users and their interactions with MH.

4 Methodology

Scotland states that “A paradigm consists of the following components: ontology, epistemology, methodology, and, methods. Each component is explained, and then the relationships between them are explored”(Scotland.J, 2012). As Scotland asserts, a paradigm holds several elements each of which create a relationship between what is being explored and how it was explored and why. He goes on to claim that methodology is concerned with why, what, from where, when and how data is collected and analyze (Scotland.J, 2012).

This chapter informs on the research design, data collection and data analysis along with the philosophical underpinnings deemed most appropriate for this research programme. Overall this thesis uses a total of 4 x case studies, presented in sets of two case studies per set. The following sections indicate the selected methods used within each case study set. However, for reader’s reference the following list outlines the list of methods used and the diagram shows how the methods relate to the case study sets. Table 21/22 describes the methods in detail for each case study set.

- (User led), Case study approach (qualitative and quantitative)
  - Think-Aloud Technique
- Naturalistic inquiry and interpretative approach
- Mixed methods Research (MMR)

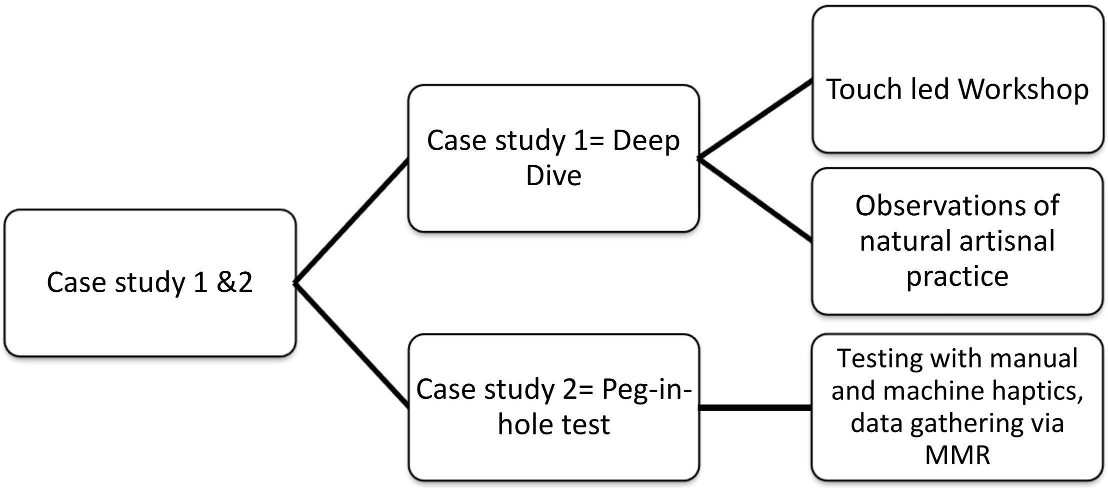


Figure 20 Hierachy diagram of the case studies 1 and 2.

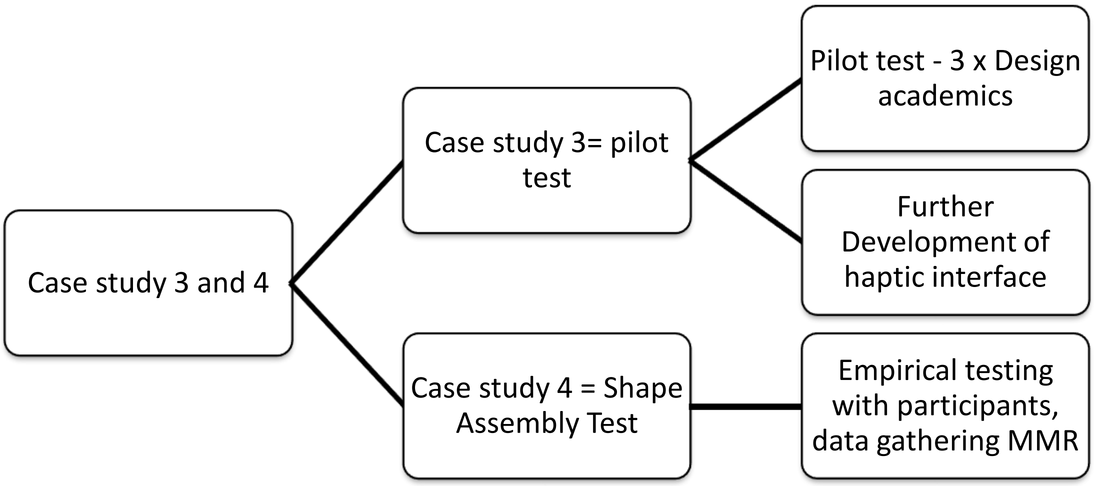


Figure 21 Hierachy diagram of the case studies 3 and 4.

Table 5 Summary of methods used for Henshaws case study 1 and 2

Choice	**Decisions**	**Chapter 5 (CH5)**
Philosophical paradigm	Naturalistic Inquiry and Interpretative stance	Section 1, Case study 1 = Deep Dive focus group
Research strategy	MMR, Inclusive principles	Case study 1 and 2 = design test set-up and analysis.
Research techniques	Semi-structured Interviews, focus group, seminars, observations, user-led development, and statistical analysis.	Case study 1, All interviews and focus group seminar sessions, DD Case study 2, all interviews and evaluations
Timeline	2013-2017	Case study 1, DD – 2013 Case study 2, peg-in-hole test 2014.
Qualitative	Focus group, observations, seminars, interviews and evaluations	Case study 1 = DD, focus group Case study 2 = Think-aloud technique throughout peg-in-hole sessions
Quantitative	Parametric data time and collision collection and analysis	Case study 2 = peg-in-hole test

Table 6. Summary of methods used for Open University case studies 3 and 4.

Choice	Decisions	Chapter 6 (CH6)
Philosophical paradigm	Naturalistic Inquiry and Interpretative stance	Section 1, Case study 3= pilot test, design lab
Research strategy	MMR, Inclusive principles	Case study 3 and 4 = design test set-up and analysis.
Research techniques	Semi-structured Interviews, focus group, seminars, observations, user-led development, statistical analysis.	Case study 3, All interviews and focus group seminar sessions, DD Case study 3, all semi-structured interviews and post-test evaluations
Timeline	2016-2017	Case study 3, DD – 2013 Case study 4, peg-in-hole test 2014.
Qualitative	Focus group, observations, seminars, interviews and evaluations	Case study 3 = DD, focus group Case study 4 = Think-aloud technique throughout Shape Assembly Test.
Quantitative	Parametric data time and collision collection and analysis	Case study 4 = Shape Assembly Test

4.1 A case for the case study

Case studies have been known to allow the researcher with a capability ‘to describe and understand the phenomenon ‘‘in depth’’ and ‘‘in the round’’ (completeness) (Evans.M., 2005).

In the field of design, the case study approach is widely accepted for many to complement action-based research programmes. Evans et al., (Evans.M., 2005) state that “Action research has been defined as: ‘an on-the-spot procedure designed to deal with a concrete problem located in an immediate situation. This means that the step-by-step process is constantly monitored (ideally, that is) over varying periods of time and by a variety of mechanisms".

In the particular case of using case study within inclusive design, The University of Cambridge clearly states that "Case studies can demonstrate how inclusive design can foster innovation and improve design."(Cambridge, 2017) By focusing in on particular nuances of user-interaction, through the use of action research using a case study model, has allowed the researcher to gain an in-depth understanding of the non-sighted art-makers and their innovative uses of crafting tools, in more depth and clearer detail. This research programme observes suggested 'best working practice' from well-respected institutes such as Helen Hamlyn Organisation and it has used their particular practice of Observation and Shadowing methods. Again this model of observational study reflects better on applied practical processes and opens up for the user to become the 'expert' and the researcher the 'shadower' /facilitator. The expert aspect of the case study, was in CS1,2,3,4 defined here as

- Staff members (Henshaws and The Open University) - persons who are professionally qualified in their field, design and support clinical and psychological practice.
- NS, VI Participants (Henshaws AMs and design students at the Open University), this study aligns itself to Newell and Gregor's theory (Newell, 2000) of the disabled participant profile to be also recognized as expert. Often individuals with such dramatic sensory loss, such as sight loss, are expert on their condition and adapting to their own needs. In that respect the individuals are able to communicate confidently on their individual ability needs with a good amount of expertise of their interactions with the world.

4.2 Naturalistic inquiry and interpretative approach

Naturalistic Inquiry dictates that the subjects need to be observed within their own setting. This allows the researcher to build up a collective 'narrative' from varied sources for example, recorded observations, interviews, user-group themed discussions and particularly for this study the interrogations of novel everyday touch versus craft processing using touch was a vital input and one which could not have been formally noted outside of the users naturalistic setting. The Interpretivist stance complements the Naturalistic Inquiry, in that, it allows the researcher to interpret the users' actions, interactions and mannerisms whilst the users are usefully engaged in daily activities in their own setting, and comfortable enough to act naturally. Using the interpretivist paradigm the researcher and the user (NS, VI Henshaws community) are able to work to identify, understand and acknowledge limitations, and to understand the user's interactions with specific tools and systems. Kaplan and Maxwell (Kaplan.B et al., 1994)state that with an Interpretive research project there are no predefined hypotheses and theories, but rather the iterative approach of the researcher and the focus group who can work to gather the body of evidence and then derive a theory from the tangible evidence and actions of users in their natural setting. Walsham's simple metaphor for this latter case is the use of scaffolding in putting up a building, where the scaffolding is removed once it has served its purpose. The purpose of using both the Naturalistic Inquiry and the interpretative approach was to construct a framework of reasoning and methodology around the case study base, once the exploratory user-led work was complete the scaffolding framework gave way to examine the events and user interactions as they were observed and recorded.

The interpretive stance examines dependent and independent variables, but focuses on the complexity of human sense-making as the situation emerges. When working with an interpretive stance it is important to understand the context as well as the individual. This enriches the 'why' question and the 'how' questions which allows further understanding of the user reactions to the tools(Kaplan.B et al., 1994). Within the DD, the how and why questions were important catalysts to probe for more detail and enquire further. For example, when observing participant craft tool handling processes in the studio, AMs were seen setting up triangulations or square formats of craft objects arrangements on the studio desk within easy reach of the AM when seated. The researchers observed this practice and enquired 'why'; one of the participants offered, through his tutor, that clustered triangulations or box-shaped clusters of objects made it easier to reach several objects located together in one-touch action. This method was observed several times by different AMs in the space of the same 4hour period. When the researcher enquired further whether it was the tutor or the participant that devised this clustering of objects process, the tutor explained that often the objects were simply assembled on the studio desks at the start of each session, and that the individual AMs would arrange the objects to suit their needs. The tutor went further to add that individual AMs object/tool assembly locations was usually consistently repeated day in day out, all object distances were carefully, but swiftly, measured by AMs using their hands to span the objects and using linear motions of their arm and hand to touch the objects. This was done to aid AMs to mentally gauge the distances from the edge of the studio desk to the cluster of objects, that way they were simply able to reach out their arm length to reach the same object every time and to replace it in the same way. Although this appeared to a layperson as a convoluted process just to use a tool, this process appeared accurate and repeatable and was actually actioned at speed.

4.3 Mixed methods research

According to Creswell , there are five elements to consider when using MMR, 1) timing 2) weighting, 3) mixing stage, 4) mixing type and 5) theoretical perspective.(Cresswell, 2009)

- Timing: The timing of the collation of qualitative data in this study was at the early phase of each of the three experimental studies, and then again at the end of the testing phases. The quantitative data for this study was collected at the start, middle and end of the empirical testing periods to enable the researcher to evidence user interactions and the dependability of the results.
- Weighting: The weighting of qualitative and quantitative methods within the overall study should be decided based on the aims of the study, the type of study and the expected results. Overall, the weighting for this study was slightly more in favor of ‘qualitative’ research, which was shown by the amount of qualitative research data gathered in comparison to the quantitative data. To understand the user’s use of MH it was pertinent to gather sizable amounts of user data and then use the data to further the development of MH technology. The results of this are discussed further in Chapters 5and6 and finally in Chapter 7, the thesis summary chapter.

- Mixing stage: The mixing stage, is when the timed stage of research is mixed with the methodology. For this study qualitative methods were used from the early stage design of the MH interface (CS1and3) and again at the end of each experiment phase (CS2and4). The quantitative methods were used to identify metric values of the haptic user task. Therefore, the quantitative raw data was gleaned from the MH rig, and analyzed alongside the qualitative analysis to produce a clear picture of the experiment.(Cresswell, 2009)
- The theoretical perspective: Cresswell et al., (Cresswell, 2009) assert that theory frameworks establish shape and connections within the research study at a micro and macro level. As stated previously the interpretive paradigm was used to guide the qualitative strategy.

The reason for using a MMR approach is that not only is this approach appropriate for smaller testing groups, but it was felt that neither qualitative nor quantitative methods alone were sufficient to fully capture the complexity of the subjects (NS users), working inclusively with the object MH technology. Therefore, the complementary nature of qualitative and quantitative methodologies has allowed for a more rounded data gathering and analysis to offer a fuller picture overall. Creswell states, “Characteristics of a qualitative research problem are…a need exists to explore and describe the phenomena and to develop theory; or the nature of the phenomenon may not be suited to quantitative measures”. (Cresswell, 2009)p.120). Quantitative data is less likely to be effective at portraying the person’s evaluations and reactions to the technology, or their understanding of the technology and how it would fit into their creative practice or even their lives. Qualitative data is much more effective at explaining and understanding human reactions and interactions. Quantitative data was more effectively used to understand the parameters and the user’s task handling, in order for the data to be consistent and reproducible.

4.4 Ethics

Ethical restrictions and protocols were duly followed for the relevant institutes involved in this study, NS,VI groups for case study 1 and 2, (UH Protocol Number: 1112/322) and case study 3 and 4, (HREC/2016/2662 and2276). Due to the nature of working with 'vulnerable' participants, due care and attention was paid to the participants' comfort, use of appropriate communication channels, and clinical working practices where appropriate. The researcher was careful to earn the trust of the participants especially at Henshaws College, and worked with this particular user group over an 8 month period prior to setting up formal research process. Participants in Henshaws were a particularly sensitive group and did not communicate readily with outside visitors in their studio. This was due, in part, to the nature of the AMs learning needs and mental health. Many AMs are not comfortable with a groups of 'strangers' and are often uneasy about presenting their artwork as they suffer with bouts of depression and anxiety. The researcher's progress, in getting the AMs trust, was occasionally slow and in the days leading up to the DD many of the volunteer working groups were unable to attend meetings about the agenda of DD testing phase due to illness. However, on many occasions the staff and AM working group more than made up for the low points through their energy, knowledge and adaptions of artisanal creation particularly for the NS community.

- **Henshaws ethics and selection:** Prior to any form of study, the plan of study was agreed with lead staff members of the Henshaws College, and a full disclaimer was completed along with consent agreements of the selected participants. Due to the learning needs of some of the participants, parental agreement was also sought to consent to their participation in the DD and testing phases. All records were kept in Henshaws and held post-test for 3 years prior to archiving.

- **The Open University ethical proposal and selection decisions:** The pilot testing and the student ethics application were applied for and confirmed. The invitation and student contact was conducted by student research project panel (SRPP). The SRPP initial selection was purely based on NS flags shown on the students' academic records, and the students were selected by random sampling parameters set within the Open University systems. The selected students were shared with the researcher via a password only access excel sheet. The final selection of students was conducted by the researcher and based on the students' knowledge of design technology, their use of CAD, and their understanding of creating a prototype, which was all established from a brief questionnaire which was sent to the selected students. All twenty participants were then sent a full information sheet detailing the background and the motivations of the tests and further details and a brief synopsis on the mechanics and technology of the MH device. The information sheet was offered as screen-reader compatible documents and in Windows and Mac compatible formats.

4.5 Qualitative data collection and analysis

Cresswell (Creswell.J., 2014) defines a research approach as "… an approach for testing objective theories by examining the relationship among variables. These variables, in turn, can be measured, typically on instruments, so that numbered data can be analyzed using statistical procedures." In this study the quantitative data approach was used to track, control, record and analyze the users' interactions using MH interface.
For CS 2, Peg-in-hole Test, the raw data came from duration (Time) and collision. Both metrics were used in M and MH peg-in-hole tasks.

Time: The time in M was digitally recorded by a stopwatch and stopped at the last insertion of hole 9 (I9) on the pegboard. The MH version of the test was timed via an embedded timer in the interface, which again timed up to when the last peg was successfully inserted in hole 9(I9)

Collision: this metric was important to assess as it was expected to highlight where the users were struggling to insert the peg in the hole, and indeed if they struggled at all. A high level of collision would show a user struggling to insert the peg, and a lower level of collision would highlight a lower level of struggle to insert the peg. A higher level of collision would also mean a greater time to complete the peg holes insertion overall. So, the collision could be one reason why the participant's time would be greater.

Quality control: Cohens Kappa was used to establish a good level of quality control on the M peg-in hole time and observed collisions. For the MH collisions and time there was a separate computerized data output sheet produced by the haptic interface programme. This was an accurate cross-check for the MH collisions and time data.

4.6 Think-Aloud technique

"Introspection is based on the idea that one can observe events that take place in consciousness more or less as one can observe events in the outside world" (Someren et al., 1994).

The Think-Aloud technique, created originally by Newell and Simon (1972), afforded the researcher a good sense of the participants' thought process, whilst working through a given task. The technique, sometimes called the 'keep talking' technique, requests that research participants externalize their internal thoughts about a given task. Participants are requested to verbalize all reactions and cognitive internal discussions externally to a research facilitator. The researcher was allowed to prompt the participant if there any long gaps in the verbalized process. Suggested prompts could be "what are you thinking?" or "what are you doing next (Someren et al., 1994). Think-Aloud, is popular amongst computer science, social sciences and creative fields of research.

In design research, specifically, techniques such as the Think-Aloud technique, are usually known as 'user protocols' and these are used to define overt behaviours within activities set by the designer for the participant. Recording such first-hand behaviours can go some way to explain internal dialogues of the users whilst they are using a product or carrying out research tasks. This type of technique can help to make empirical activities more transparent to the researcher/designer. The Think-aloud technique adds a personalised accent to the users behaviours which may then latterly be compared and translated or deciphered and taken forward into a different developmental stage e.g. concept page of drawings or sketches by the designer as a visual evaluation of users recorded interactions and issues with a particular product, voice recordings can be used to decipher users honest and personal understanding of their interactions with products. The Think-

Aloud technique offers users account of their pros and cons of an interaction, offering the designer rich discourse to be reviewed and may be discussed latterly.

In the context of Henshaws AMs the think-aloud technique was used to allow AM's creative passions and voice through within the observation period as well as within empirical haptic testing to allow the researcher to better understand the users experiences and understanding of the haptic process and tooling .

The types of data collected were, background detail, observations on how AMs used manual touch on a daily basis, and on their creative working process. The qualitative results were recorded and taken forward to support the development of a user-led haptic interface, as shown in case study 2 (CS2). (See chapter 5 for full details).

In the context of Open University design students and design academics were requested to use the think-aloud technique in case CS3 and 4. The think-aloud data was recorded and transcribed and processed sampled coded and analysed using NVivo (21 v). (See Chapter 6 for full details)

4.7 Summary

This chapter has clearly set out the theories and methodologies, motivations for the selection of the methodologies used in this research programme and how and why they underpin this thesis. The information shown here is hoped to reflect the methods to enable the gathering of data on the nature of NS, VI user and human/machine haptics, and the interactions between the two elements. It is also hoped to have clearly shown how the two main elements were examined using the Naturalistic Inquiry and Interpretive paradigms, and why MMR was used to collate and analyze the data.

The following two chapters are the empirical research chapters. The information and detailed reviews provided in Chapters 1-4 should act as a background to Chapter 5 (Deep Dive test and Peg-in-hole test, Henshaws College) and Chapter 6 (The Shape Assembly test, The Open University). All analysis and discussions can be seen at the end of both of these chapters and further discussed in Chapter 7.

5 Art-maker case study 1 and 2

It has been outlined, in this thesis, the importance of touch in the human body and how humans perceive touch in a completely different way than other senses in the body. Through the review of MH literature presented in Chapter 3, it has been shown how machine haptics have been used to increase inclusivity to encourage particular groups of disabled individuals to interact with VR in a more innate manner. This thesis, thus far, has shared the reasoning behind the need to facilitate a wider body of users of VR, with an easier access to aid training/learning.

This chapter commences with a layout of inclusive design principles and goes on to describe case study's 1 and 2 (CS1 and 2). The first case study (CS1) outlines the Deep Dive (DD) action-based study, based around inclusive principles. The DD was sectioned into specific sets of tests which were designed to culminate into data which can be analysed to gain a clearer picture of user. CS1 users are NS, Art-makers (AMs) located in Henshaws - Art and Design Charity, Yorkshire. The second case study (CS2), featured in the second half of this chapter, reports on the empirical work set around a clinical trial fine motor skills trial, aka Wade's peg-in-hole test (Wade. D.T, 1992). Users' feedback from both case studies are presented along with an analysis of qualitative and quantitative data.

5.1 Inclusive design principles

The CABE principles[15] advise that designers should consider a breadth of user needs, shown within their user focus group. The following shows the Inclusive design rationale which underpins the DD study:

[15] CABE – Charted Association of Building Engineers is an association featuring a blend of architects, inclusive designers, and engineers.. CABE. 2017. *CABE principles* [Online]. CABE. Available: https://www.cbuilde.com/the-cabe/ 2017].

The Principles of Inclusive Design

1. Place people at the heart of the design process
2. Acknowledge diversity and difference
3. Offer choice where a single design solution cannot accommodate all users
4. Provide for flexibility in use

The CABE Principles in detail

- People – It is important to involve as many people as possible in the design and development process in order to develop sustainable communities and to help to promote personal well-being, social cohesion and enjoyment.

- Range – As many people's needs as possible should be met, such as mobility impaired, visually impaired, hearing impaired and those with learning difficulties or mental health issues. These are all part of a diversity of people who can potentially face barriers.

- Choices – Choices should be given 'where a single design solution cannot accommodate all users'. This clearly acknowledges the diversity within impairment groups and that individual needs may differ. It also recommends designing beyond the minimum requirement.

- Flexibility – Flexibility is important in inclusive designing. It emphasizes gaining an understanding of the purpose of the space or building and who its users will be, with a view to adapting to changing demands.

- Widening scope - Inclusive design means going beyond the physical attributes. It talks about 'intellectual' and 'emotional' access through information being available, including prior to visiting a building. (CABE, 2017)

A select few points from CABE's inclusive principles were reviewed prior to the DD and were attributed to the planning and rigor behind the DD study and the test design. Many of the research models and the accessibility inclusions of the DD study were then cross-referenced to the CABE inclusive design principles for example, flexibility, of space and flexible approach to users' physical comfort and fatigue needs.

5.2 Aims and Objectives (Deep Dive)

The Deep Dive study is aimed to allow a deeper understanding of the user group. This project aimed to investigate everyday practices of the AMs within their own studio environment, Henshaws, in Yorkshire. Although the studio building was purposefully built for non-sighted AMs, the researcher was particularly interested in the AMs own inclusive additions and adaptions to their own space and environment to aid their creative practice. Due care was paid to diligently follow Henshaws ethical practices (shown in Chapter 4) whilst observing and studying AMs, the project followed an inclusive design framework aimed to empower AMs and give them space to voice their own thoughts with ease. The following provide a list of aims and objectives for the DD project.

Aims

- To co-design an inclusive testing schema which would successfully investigate whether machine haptics would offer particular affordances to NS, VI art-maker community.

Objectives

- Using the case study Naturalistic Inquiry approach, observe and interview art-makers to further understand the nature of Art-makers work with crafts process.
- Using specifically inclusive designed tasks and activities explore which design principles facilitate NS user-led interface.

5.3 Participants focus group

As previously stated in Chapter 4, a great deal of preparatory work was undertaken, using a theme which Newell defines as 'an Extra-Ordinary user'(Newell, 1999). This simply means that, prior to any formal DD or MH testing the working relationship with AMs was paramount to ensuring that the AMs extra ordinary abilities became apparent. Therefore, a user test agenda was set; the following demographical details describe the user group of NS to VI AMs, who volunteered to work with the researcher to further understand their touch-led abilities and limitations.

This study worked with five volunteers, all with varied sight acuities and varied learning needs. The ages ranged from 19-29 years, mean average age of 23.4yrs. The focus group was recruited with the guidance of Henshaws lead managers and clinicians. The list for recruitment was made up of AMs who offered to volunteer for the DD study, and to work with the haptics tool. The focus group members were used to speaking with external visitors as they had previously worked with professional artists and designers, and medical researchers.

Table 7 Deep Dive focus group participant details

		Usability testing, participants Deep Dive,	
Participant number	Gender (F/M)	Dominant hand (L/R)	Sight acuity and clinical condition
No 1	F	R	Non-sighted, Down Syndrome
No 2	M	R	Non-Sighted, Down Syndrome
No 3	M	R	Severe visually impaired, Asperger's
No 4	M	R	Severe visually impaired, Learning needs
No 5	F	R	Non-sighted, severe learning needs

5.4 Deep Dive Design

The DD study was designed around inclusive principles and used a qualitative research approach. The first stage (stage 1) used an IDEO inspired focus group workshop to discuss DD study elements. The next stage (stage 2) used PICTIVE process, group members were requested to layout everyday 3D objects as a design template for the MH interface. Throughout the DD stages participants were requested to use the **'Think-Aloud'** technique, e.g. during manipulating mediums and materials, use of art tools, organising and orientating tools on the art bench. The final stage (Stage 3) was a Likert questionnaire set around tactile interactions and their thoughts on the feasibility of haptic tools. The following diagram presents a flow diagram to highlight the structure of the DD study.

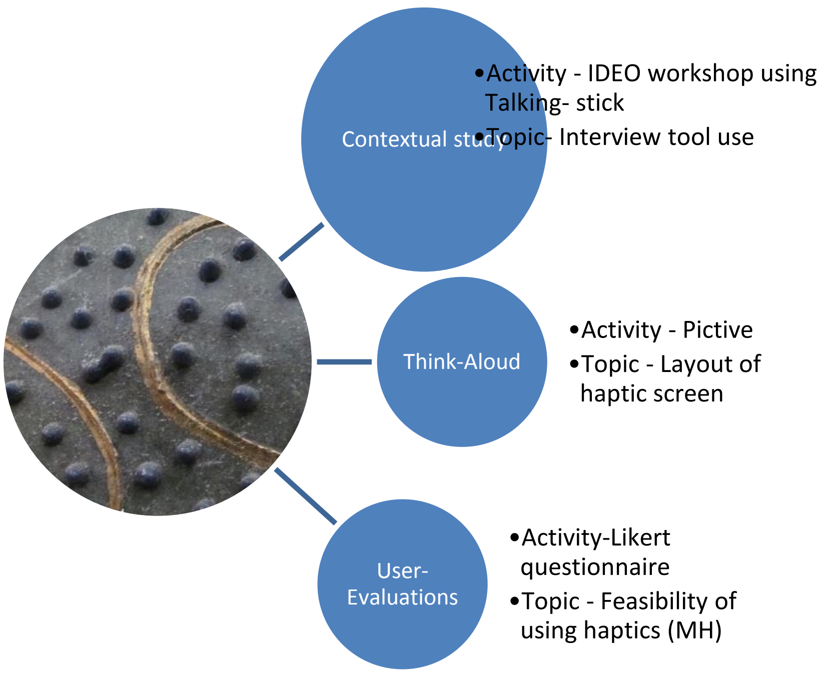


Figure 22 A diagram of the Deep Dive structure and interlinking activities

The AM focus group were advised about the theory and aims behind the DD and encouraged to actively feedback to the researcher.

As part of the ethics process the focus group members were informed that clinical staff were available at all times and when the researcher entered the focus groups working space they introduced themselves to each member before commencing the day of observations.

5.4.1 Deep Dive IDEO principles

The first stage of the DD was designed around IDEO[16] concepts, starting with a clear statement of the guidelines of the first session.

- Everyone has something valuable to say, a story to tell, and this was stated as extremely relevant to the process, so everyone was encouraged to listen and everyone's input would be heard and noted, no matter how small.
- Every individual should consider others' ideas and think about how to build on that idea
- There would never be one solution, at this stage, as it was an information gathering exercise

To stay within an inclusive model, all users' feedback, at this stage, was deemed valuable and so a communication system (aka a Talking Stick) was used to provide all users a clear channel to communicate their needs.

5.4.2 Deep Dive (communication)

As all AMs in the user focus group were either blind or severely visually impaired (SVI), managing everyone's verbal input, taking turns to speak, was an intricate process. That is to say, some blind individuals cannot tell whether someone has finished speaking or is just pausing in their speech, as they cannot physically see the visual clues such as body language or facial clues. This can create some individuals speaking over each other, and getting frustrated or even refusing to speak. Therefore the researcher utilised a 'Talking-Stick' to organize communciations in the IDEO workshop. A talking stick is a tactile communication aid, designed to

[16] IDEO – USA based, internationally known, design practice company, said to be the most influential designers of the 21st century.

facilitate turn-taking. The rules for use are 1) each participant can hold the stick for no longer than 10mins, 2) a participant must pass the talking-stick to the left after speaking, and 3) only the individual holding the stick can speak. A Talking-Stick can also benefit more reticent participants to voice their opinions, as they will always get caught up in turn-taking. Overall, the Talking-Stick was used to make a clear channel of communication within the group, thereby allowing more vocal group members to listen as much as they spoke. The themes within the Talking-Stick sessions were: **assisting tactile tool use**, **learning effective touch orientation** and **working with art making processes** via touch and sound.

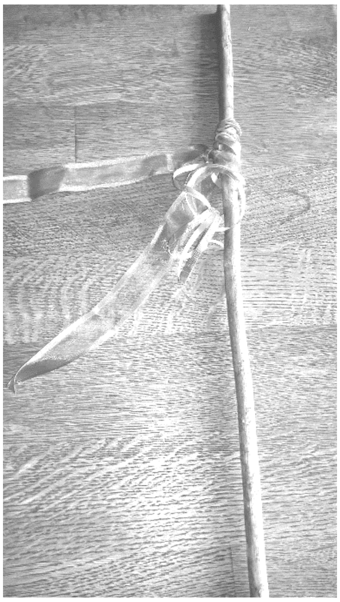


Figure 23 Talking stick: source authors own

After the Talking-Stick workshop, a semi-structured interview was designed around tool use, entitled ‘objects and touch’. One of the themes from discussions was that being trained in touch-led processes allowed better autonomous freedom of movement, in the studio and at home.

5.4.3 DD - Tool use

Inspired by seminal works on NS/VI artists and their handling of tools and drawing by John Kennedy (Kennedy.J.M., 1996), the DD stage 1, tool use aimed to gather user-led observations and feedback on the topic of tool use and navigation of studio workspace. Working further in the concept of objects and touch, the group members were requested to express how much they enjoyed selecting and using 'their tool', a tool that had been specially picked out by them for their needs. The AMs would initially learn how to use this tool to express their own creative language. Group members were keen to describe how they favored having one single tool, over a selection. They added that they used their one tool for various creative process. The reasoning for the use of a single tool is that AMs do not have to put down a tool and pick up another, as picking up another tool means extra time searching it, picking it up and using it. All of this extra time extended the completion of a piece of work. Instead, they chose to use one tool in a variety of different ways. This notion of one tool use, as a multi-functional tool, was interesting, as it worked against design practice 'norms'.

Traditionally, designers use a specific tool for a specific purpose and often there are a wide selection of different tools at the designers' disposal. Thereby the AMs' tool use was novel but pragmatic.

5.4.4 Studio observations

The focus group of AMs were requested to work on their art pieces as they usually would, and during this time the researcher would record and note studio observations. The research facilitator observed the whole group and their navigations and use of the studio space; the observations were sub-divided into the following sections:

1) *Orientation:* The mechanisms used to orientate around the studio space were observed and mechanisms used to orientate and find objects on the desktop were noted. AMs were often observed touching and feeling in vertical or horizontal linear movements across a desktop, or on to the edges of the design studio. A linear form of orientation is a more constructed accurate way to cross a wider

space. Within the studios AMs knew that a clear pathway would always be available for them to walk around safely and easily.

2) *Active hands:* AM hand movements with and without tools were observed. Nuances of touch examined grip of tool and home cue use. Six group members showed well practiced linear (horizontal and diagonal) hand movements to find tools on the desktop. One AM was new to the studio and was observed repeatedly trialing the outer perimeter of the studio, to allow himself to remember the route. All five members of the group showed use of home cues and work-space boundary lines, meaning that they used particular common objects (pebble, notebook or weighted container) to demark a 'home' cue in their desk space. The home cue was usually located in the bottom left-hand corner or the top right of workspace desktop. The home cue was used to give AMs a consistent cue point to return to and a place to leave their tool allowing for a more efficient tool pick up point. The boundary line demarcation was shown in the form of a washing line taped to the desktop. The boundary line was scaled for each AM, and measured by the AMs physical reach vertically and horizontally.

5.4.5 DD (Stage 2) PICTIVE - peg-in-hole task

Wade's peg-in-hole test (Wade. D.T, 1992) (aka nine-hole-peg test - NHPT) is a recognized clinical test to assess rehabilitative needs in a stroke patient. The standard use of the NHPT would be conducted as part of a stroke rehabilitation program. The peg-in-hole task was also selected for its brevity, repeatability, and its links to assessing fine motor skills. This was considered to be the main aim of the M and MH version of the peg-in-hole task. The assessment of how accurately NS AMs could drop nine pegs into nine holes using the MH would go some way to understanding the appropriate use of MH for NS individuals.

The standard commercial peg test kit (shown in Fig. 22) is an example of the kit given to AMs, to use whilst working through the 'Think-Aloud' technique. The AMs were then requested to design a physical 3D mock-up peg board which would use the principles of a PICTIVE, a tool which was familiar to the AMs. A PICTIVE[17] is a common way to allow user (NS individuals) to touch and interact manually with objects which could be used as representations of real-world objects or environments. For example, PICTIVES are used as wayfinding tools so NS individuals can scope a mapped area prior to walking through it. The following Figs 24 and 25 present various forms of PICTIVES created by the group to represent the Peg test as a design for potential MH interface designs.

Figure 24 standard commercial peg test apparatus

Figure 25 a) Option 1-2 PICTIVE of Wade's NHPT, materials were a deep cardboard box, wooden pegs in varied formats. Source: author's own.

[17] Plastic interface for collaborative technology initiatives through visual exploration (PICTIVE) is a paper mock-up technique that permits users to take part in the development process. – cite from Technopedia (accessed 2018)

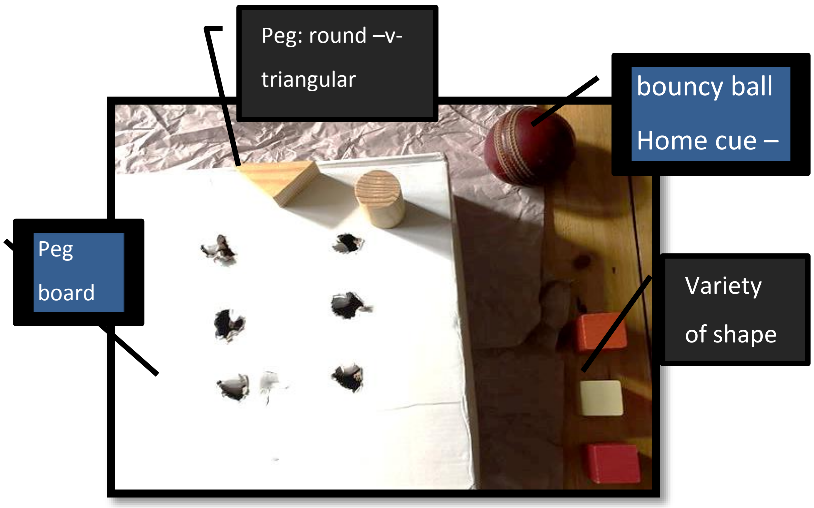


Figure 26 PICTIVE which has been analyzed and transcribed to show how it will relate into a virtual layout (DD author's own)

The Think-Aloud current protocols were given to the AMs prior to the construction of the PICTIVES. They were interesting as they not only informed the location of the object they were placing but also the reasoning behind locating the object. AM1 stated "I am going to put this box here, right in front of me, so I can touch it again quickly if I need to.."(AM1, 2013) it is interesting to note that three of the AMs vocalized thoughts prior to the movement of hands e.g. when they were not moving and not grasping objects, AM2 stated "So … erm right…I am going to move my hand to get a wooden shape now…" Appendix A6 - (YSJ, 2012) The vocalization of hand movements was interesting as participants were never asked to vocalize hand movements, but some members offered that it helped them to externally vocalize their hands touching and moving.

5.5 DD (stage 3) feasibility Lickert questionnaire

Gathered back at a meeting room space the group gathered around a seating area and were requested to imagine using the proposed haptic device. Using a PHANTOM Omni® haptic device, the group were encouraged to individually touch and explore the device whilst it worked through the example dice game. This was to set up to allow the group to create a mental image of the device and feel the guiding forces of the device. The researcher delivered a set narrative regarding the uses and working process of the haptic device. It was explained that the haptic device would mimic real-world touch feedback of 3D objects in virtual space. The device would allow users to be guided to pick up and trace virtual objects. They were asked to respond to four statements to grade how important each statement would be to them. The questionnaire used the Likert Scale to grade the statements. (Scale =1 no agreement -5 fullest agreement). The four statements were adapted from a SUS questionnaire and each statement was read out loud to the group members by Henshaws staff, thereby no emphasis could be given to steer the group in to any form of bias.

5.5.1 DD Qualitative results

The feedback from the Talking-stick sessions, ‘touch and tool use’ showed an overall insistence for each group member to take their time to feel an object for themselves, without intervention or interruption from a sighted family member, Henshaws staff, or even their own AM peers. AM 1 stated,

“I don’t like the others here to tell me what some’mat’ [sic] feels like. I like to do it fo’ m’self [sic].” (AM1, 2013)

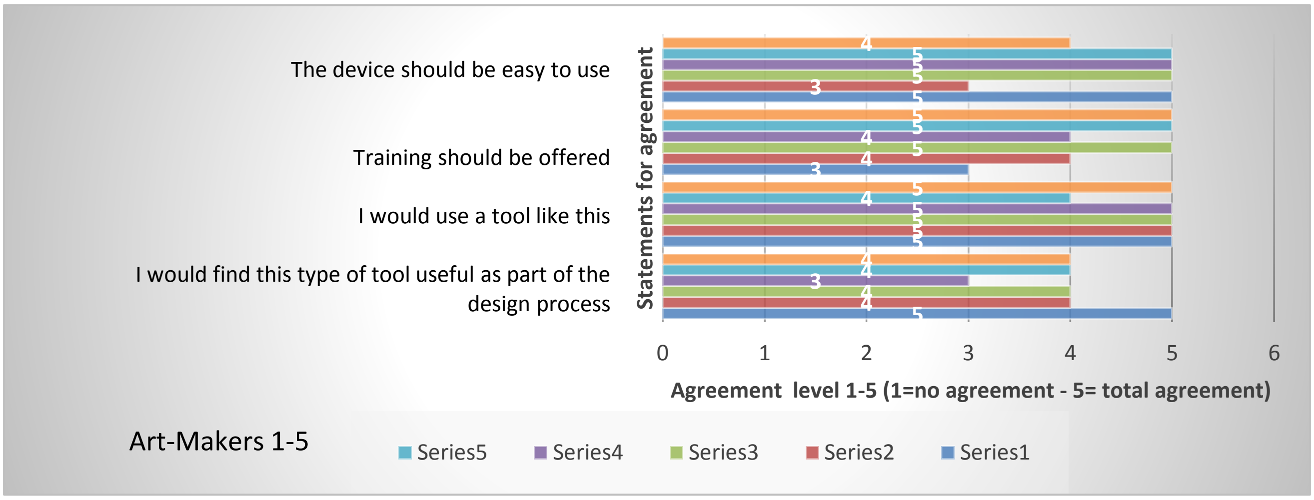
and AM 2 [90] responded,

“ yeah, mi too[sic], I’m like that. Mi’[sic] mum picks things up and passes [sic] them to me, an’ it drives mi’ mad. I really don’t like it! I like to search in my own time for my own things for m’self [sic] then I get to search more…and I like doing that.” (AM2, 2013) *(Transcribed discussion samples on Appendix (X))*

During discussions on tool use, AMs were keen to express how they preferred a tool which “felt ‘nice” in their hand. When selecting a tool group members stated that they were wanted to select a tool that felt familiar, had a good weight in the handle, or the handle “felt warm” or had a familiar coating (patina) when touched. The AMs expressed how, over time, they had utilized their single tool for new and varied tasks for example, a paintbrush to draw (handle) and to paint (brush). A scraper knife usually used to take paint off, was used by AMs to put paint on, or to flatten surfaces and fix collage pieces. The discussions were very enlightening and extremely useful, the versatility of single tool use was unexpected and against ‘classic’ process practice.

The questionnaire responses were reasonably positive, in that many of the group showed total agreement with the statement that they *would* use a tool, such as the haptic tool and they would find the tool useful as part of the design process. The lower levels of agreement were made by the single individual who was new to the studio, and he latterly explained he had not really understood the manual design process so could not really consider digital tools.

Table 8 AMs user-led input for the nine hole peg test design



5.6 Case study 2, Nine Hole Peg Test

The affordances of haptics for NS users, when used as part of an assistive tool to complete tasks in the virtual realm, has been discussed earlier in this thesis. The following report of case study 2 (CS2), explores the impact of a haptic device and rendered interface to complete Wade's peg-in-hole test.

This section through to the end of this chapter reports on CS2, and examines NS participants and FS (as control) participants interactions with M and MH peg-in-hole task. The MH version of peg-in-hole used a PHANToM Omni haptic device (currently known as the Geomagic Touch™).

To allow for NS, FS inclusive interaction during CS2, 'an adapted, nine-hole-peg-test interface' was needed to offer the following usability points:

a. Ease of use.

b. Training given prior to the main trial. A pre-trial two-hole pick-up and put-down peg task was designed.

c. The NS users to be guided by force additions, via the haptic device.

5.6.1 Machine and manual peg-in-hole experiment

This section of the chapter reports on two experiments both using the Phantom Omni device used by selected sighted and non-sighted user groups. The experiments were framed by research question (RQ1), - re-presented for reader reference, as it pertains to this particular experiment and this chapter.

> **RQ1:** Can a novel haptic design application, be used to assist non-sighted(NS) 'Art-Makers'(AMs) to interact with virtual reality environments (VRE's) when aided by multimodal assistance?

The motivation behind selecting the peg-test was that it was its brevity, easy to reproduce, simple set-up, easy to understand, and it held potential to adapt the classic method to suit the NS user's needs. The following outlines the classic Wade's test used across rehabilitation fields as a simple motor skills test. It then describes the adapted peg-test used in this study, M and MH descriptors are presented. The rest of the chapter reports on the pilot test and main empirical test and finally presents findings and discussion.

5.6.2 Wades Test Manual descriptor

- Nine-hole Peg Test original (NHPT) (Wade. D.T, 1992)
- Used as a repetitive measured fine motor skills test for neurological patient rehabilitation

<u>Original Wade's peg-in-hole protocol</u>

The patient is to be seated at a table, and asked to place nine pegs into nine holes and then retrieve the pegs within a standard time (18.5 seconds). Observer times from start to end of test, but can stop at 50-100 sec and record number of pegs placed. Peg-in-hole test has been clinically recognized for its reliability, brevity and repeatability.

5.6.3 Adapted manual peg-in-hole test and apparatus

The adapted manual peg-in hole test was modified for NS participants, in that participants were requested to only place the pegs into the nine holes, the participants were not requested to then retrieve the pegs as per Original Wades Test (1992). Seated at a standard height desk, in front of each participant was a wooden based rig where the NHPT was embedded including a peg housing to the right side of the rig and the nine hole board placed in front of the MH haptic device, Phantom Omni. NS/S participants was requested to take one peg at a time for the peg housing and place it in the nine hole board (sequentially in a horizontal direction left-right). On pick up of the first peg the participants were timed throughout the test until the last peg (peg 9) was placed into the last hole (hole 9). The participants were recorded throughout the peg-test. The recordings were later used to analyse the peg-hole collision count for each iteration of the test. For quality Cohens Kappa formula was used with two inter-rater's to confirm the collision count for each participant.

Apparatus Descriptor:

- 9x wooden dowels; *(9 mm diameter, 32 mm long).*
- 1x wooden base with 9 drilled holes *(10 mm diameter, 15 mm deep),* each hole spaced 15 mm apart, three holes per line.

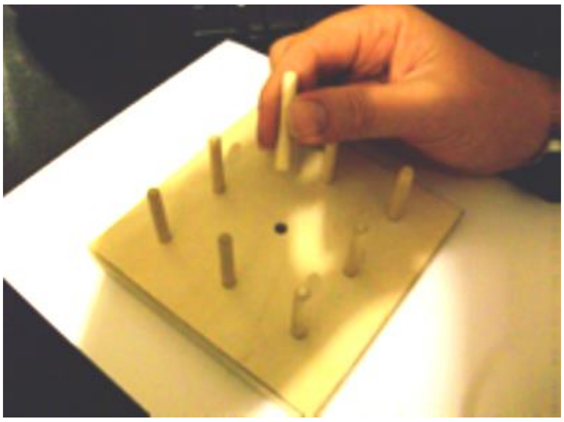


Figure 27 Manual adapted Wades peg in hole test (source: authors own)

Adapted machine haptics (MH) peg-in-hole:

Apparatus Descriptor:

- *9x wooden dowels; (9 mm diameter, 32 mm long).*
- *1x wooden rig base with 9 drilled holes (10 mm diameter, 15 mm deep), each hole spaced 15 mm apart, three holes per line.*
- *1x Phantom Omni haptic device*

Figure 28 Peg in hole test, in embedded rig housing, design by researcher

Figure 29 Haptic device being used by participant within peg in hole test (source: own image)

5.7 Method – Machine Haptic, Peg-test

Seated at a standard height desk, in front of each participant was a wooden based rig where the NHPT was embedded including a peg housing to the right side of the rig and the nine hole board locked to the desk near-side edge, directly in front of the MH haptic device, Phantom Omni. NS/S participants was requested to hold the haptic device stylus in their dominant hand and hold the end effector on the home cue (a sphere which was given a 'bouncy' rubber ball feedback). On pick up of the first virtual peg and place it in the wooden peg board. Upon pick up participants would hear a loud 'ping' on insertion into the nine hole board the participants would hear a ping with a slightly higher timbre. All participants were timed, by the haptic application, throughout the test until the last peg (peg 9) was placed into the last hole (hole 9). The participants were recorded throughout the peg-test. The recordings were later used to analyse the peg-hole collision count for each iteration of the test. For quality Cohens Kappa formula was used with two inter-rater's to confirm the collision count for each participant.

5.7.1 Peg-test conditions

The peg-in-hole MH rig, offered three conditions (rig1-3); each participant was given a full explanation about each rig condition from a script, prior to commencing with the tests. Each participant was requested to grip and hold the haptic stylus in their dominant hand (assessed prior to the test commencing). Each participant was given a few moments, prior to starting the test, to locate and feel' the sensation range of feedback from the virtual home cue, for example, home cue had a spring-like feeling, likened to a rubber ball. The concept of using a home cue had been lifted from the CS1, DD and used as a familiar start and finish cue. Once the participant was located on the home cue, a digitally pre-recorded (speech) countdown commenced for example., "1, 2, 3… go..." Throughout the trial participants were requested to try to have minimal contact with the wooden peg board and rig via the stylus endpoint, to avoid too many unnecessary collisions. Participants were asked to start at the top left hole (hole 1) and work left to right across each line of three holes working down the pegboard until hole 9. Table 9, highlights a synopsis of the test conditions for each rig.

Table 9 Table of test sequence of each rig conditions 1-2, Rig 2 is adapted rig max haptic and assistance

rig	*Iterations numbering*	*Conditions*
rig 1	4 (I1,I2,I3,I4)	1. force present 2. *small* virtual target holes 3. audio speech 4. non-speech sounds.
rig 2	4 (I1,I2,I3,I4)	1. force present 2. *larger* virtual target holes 3. audio speech 4. non-speech sounds.
rig3	4 (I1,I2,I3,I4)	1. *decreased force* present 2. *decreased* virtual target holes 3. audio speech 4. non-speech sounds.

5.8 Participants

Participants were invited to take part with the manual and MH version of an ‘adapted Wade’s Peg-in-hole test, (n=3) NS (clinically classified as blind) and (n: 3) FS. NS and FS participants were recruited from a local charity Henshaws College Institute. All participants had different educational backgrounds; this was a mix of special needs schools and mainstream for the NS and mainstream for FS. Table 8 shows the gender and age range of the participants and their hand dominance.

Table 10 Demographics of participants (Henshaws) Peg in hole test

Participants subgroups	***Participants***			
	Gender (Male=m, Female=f)	***Age. (Years)***	***Dominant hand right =r left=l***	***Participant numbering code***
Non – Sighted (NS)	2 = f , 1 = m total = 3	30-40	3x r	NS1,NS2,NS3
Fully Sighted (FS)	2 = f , 1 = m = total=3	30-40	3x r	FS1,FS2,FS3

All participants had previous knowledge of, or were familiar with, using a standard commercial desktop computer to an extent, but none of the participants had ever used any form of haptic device, such as the chosen Geomagic Touch device, prior to this study. Training of the Geomagic Touch device, was given to all participants prior to using the tool, via a pre-trial haptic test. The pre-trial training was given to make sure that the participants were being tested on the interface and not their use of the Geomagic Touch device. The 'Guided Discovery' model[18] was used to steer the training and to that end all participants received the same guidance from a script, and each participant was allowed time out to reflect or rest, prior to committing to the tests and throughout the duration of the tests. However, no participant requested to take rest breaks at any time during the testing.

[18] Students discover knowledge without guidance, developing their own understanding. Shrager and Klahr 1986)." (Stephen Bostock), retrieved, 17:17, 15 September 2006 (MEST). (accessed via wiki –Oct 2017)

5.9 The validation of using machine haptic with peg-in-hole test

In recent years NHPT has been lifted away from being a purely manual test and has also been used in the virtual realm (VR). Particular reference here is given to previous studies by Amirabdollahian and Johnson., (Amirabdollahian and Johnson, 2011) and a more recent study by Bowler, Amirabdollhian and Dautenhaln (Bowler, 2011) . To date, there have been no other studies that the author is aware of, using peg test (MH) adapted for use by NS individuals. Amirabdollahian and Johnson (Amirabdollahian and Johnson, 2011) study uses an adapted Wade's NHPT within a rehabilitative context. The test rig was developed to offer real-time changes to be made to peg diameter, peg height, peg weight, hole diameter, separation distance between holes and clearance (peg vs. hole) thus allowing the creation of more dynamic virtual environments. A later variation of the peg-in-hole test prepared by Bowler, Amirabdollahian and Dautenhahn (Bowler, 2011), allowed for an exact replication of the clinical NHPT using the haptic tooling, used in the context of rehabilitation assessment.

5.10 Pre-trial training of peg-in-hole test and machine haptics

All participants were requested to complete at least two trials of the pre-trial training test, prior to the main test, the pre-trial test was a shortened version of the main peg-in-hole test and designed to allow users to become familiar with the unique feedback from the haptic device.

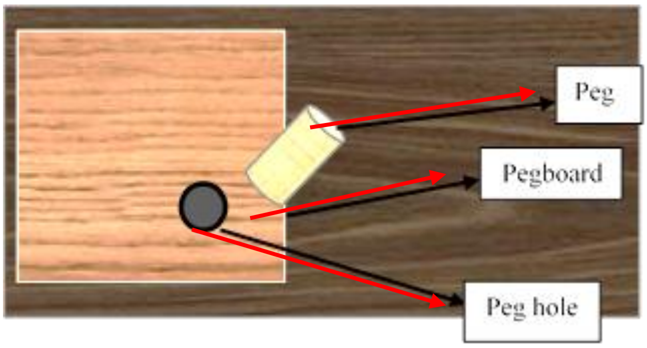


Figure 30 Representative graphic of peg in hole pre- trial

5.11 Developments of the peg-test *(mark ii)*

A preliminary quality NHPT was conducted by 3x NS participants prior to the main testing study. The results showed that the times taken to complete the peg insertion into hole nine (I9), were not aligned to 50sec time limit for Wade's test. A poor average time was taken for the user to pick up the first peg and place it in the final hole nine. Time average was *(>80.3 secs*), it was deemed this time did not reflect the potential of the haptic rig and so adaptations were developed to lower the average time closer to the Wade's test standard average time *(18.5 seconds)*. Therefore, a new iteration of peg test (*mark ii)* was developed and this iteration was used within CS2 peg-test experiment. The table below references the inclusive issues and the adaptations made to allow the haptic rig to be more usable for NS participants.

Table 11 User Issues and MH adaptions from Mark 1-2

User- Issue	Adaption
1. Issue -The use of an embedded physical haptic pegboard did not allow the NS users to place the peg in the hole easily, without too many collisions	Response -A larger circumference of the peg hole was created within the interface. This was connected to the coordinates of the physical peg-board, therefore allowing the user to touch the edges of wider peg-hole with the physical peg and the peg was considered inserted in the hole by the interface.
2. Issue -Users felt little force driving them to place the peg in the hole.	Response - Offered a range of forces to increase speed to hole.
3. Issue -Users requested more speech sounds mixed with non-speech sounds (pings / bings) to denote to them more of a multimodal experience.	Response - Added speech sounds at the beginning and end of the test, and non-speech sounds to notify user when the peg was inserted correctly to allow them to collect another peg. Previously it appeared the users were waiting for the haptic to drive them to the next peg and the length of waiting for 'something' to happen resulted in a larger overall time.

5.12 Qualitative results haptic peg-in-hole test art-maker feedback

Results from rig test 2, showed the greatest difference between time values and between subgroups. The NS participants' results from empirical recordings of interactions with rig 2, showed that they had no real motor skill control or orientation difficulties with this rig.

When compared with the qualitative feedback it could be seen that the NS participants endorsed this,

"I liked this second test the best [sic].." (1-3, 2012)

"…why can't I just work with number 2?"

Sighted participants stated," I missed the force from rig 2.. as in rig 3 I just didn't feel it… it was just like a car which wouldn't start… is that correct?"(1-3, 2012)

" I liked the pushing force, I felt it like wham…[sic] all of a sudden (laughs) and I got pushed to the block…straight away…[sic]." (NS2 2012)

The post-test review provided NS/FS participants with a chance to communicate reflections for all rigs,

"I felt that the number 2 rig, was much better than my last test set [sic]." (1-3, 2012)

"The second one please [sic], it was easier to work with, it had more sounds and…[sic] well.. just easier, I guess" (NS2, 2012)

"My personal favorite was no. 2, that's the one that I would use again" (NS3,2012)

Multimodal haptic interface and haptic augmented tooling, was expected to increase speed and efficacy of participant use, compared to the non-assisted NHPT. The results reveal that the hypothesis one (H1) was in fact realized from results taken from rigs 1 and 2. Rig 3, designed specifically to test the acceptable boundaries of haptic use, with less haptic cues proved inefficient compared to rig 1 and 2 which offered better results as they had the force assistance. Although the FS and NS participants did struggle with rig 3, NS participants, without exception, equally recorded an increase in time from initial peg insert to final peg insertion, as well as qualitatively NS1 offered that,

"…the last one really frustrated me.." (NS1,2012)

They went on further to say,

"..I found I was waiting for guidance, but it never came." (NS1, 2012)

It can be said, through analyzing qualitative feedback, that once the NS participants became accustomed to using the haptic tool, they became conscious of the force feedback sensations and expected to feel this on every interaction with peg test rigs. When the force feedback and guidance was reduced the users felt the difference and communicated that the feeling of the maximum force made the augmentation of touch more convincing than without it.

5.13 Collision coding and its intra-rater validation

All of the peg-in-hole M and MH were video recorded and coded afterward to assist with analysis of collisions of the end effector in the peg hole or pegboard. Cohens Kappa (McHugh.M, 2012) was utilized to understand a measure of quality of agreement between two inter-raters[19].

[19] An inter-rate is a second observer of recorded material, the inter-rate views a reduced version of the test facilitator and indicates where coded events happen e.g., collisions.

Table 12 Table showing inter-rater difference in collisions observed for iterations of all rig conditions

Rig 1				
Participant	Rater 1 Collisions	Rater 2 collisions		Different between rater 1and2
1	4	3		-1
2	5	5		0
3	6	6		0
4	4	3		-1
5	5	5		0
6	6	7		-1
Rig 2				
1	2	2		0
2	3	2		-1
3	3	4		-1
4	4	3		-1
5	5	5		0
6	5	4		-1
Rig 3				
1	5	5		0
2	5	4		-1
3	6	5		-1
4	5	5		0
5	6	6		0
6	5	5		0

Interpretation of Kappa

Poor Slight Fair Moderate Substantial Almost perfect

Kappa Agreement

< 0 Less than chance agreement

0.01–0.20 Slight agreement

0.21– 0.40 Fair agreement

0.41–0.60 Moderate agreement

0.61–0.80 Substantial agreement

0.81–0.99 Almost perfect agreement

50.0% (M.Avg) = Moderate Agreement for collision metrics

Resume of proportional agreement and average agreement

Total count of 0 in difference column =	9
Total ratings =	18
Proportion agreement =	3/6, 2/6, 4/6
Percentage agreement =	50.0%, 33.3%, 66.7%
Overall percentage agreement = (mean)	50%

5.14 Results

- Duration and collision

The approach used was to examine results for duration of each participants NHPT with each rig. The average mean and std dev. Is summarised in the table below (Table 38).

Table 13 Mean avg peg in hole test, FS,NS, rigs 1-3 duration and collision

Duration nCollision * Rig

Rig		Duration	nCollision
Rig 1	Mean	16.2917	12.6250
	N	48	48
	Std. Deviation	8.86532	2.16967
Rig 2	Mean	11.3125	13.1250
	N	48	48
	Std. Deviation	5.45838	3.04313
Rig 3	Mean	24.3542	18.5833
	N	48	48
	Std. Deviation	13.23517	5.53455
Total	Mean	17.3194	14.7778
	N	144	144
	Std. Deviation	11.05780	4.68959

Table 13 suggests that Rig 2 (with full multi-modal assistances) yields better mean averages overall (duration/collision) user results for both groups. Rig 3, without assistances, has the highest averages for both groups overall. Analysis of recorded durations were carried out between groups using one way analysis of variance (ANOVA) in order to review the intergroup differences as measured by the performance time. From this a statistically significant result ($p < 0:001$) was attained. This indicated that based on the performance time measured, participant groups differed significantly. This included the full 12 sets of data per participant group. The next step was to ascertain if there were significant differences between different iterations. An ANOVA model with duration as parameter and iteration as factor returned statistically insignificant differences ($p = 0:802$). Thus it was possible to consider the results for all four iterations. Additionally, a second ANOVA considered differences between the BM/EM measurements that were recorded with a one month separation to consider learning effects. As there were significant differences shown by the results (p < 0:0005; F =23:604), it was reasonable to separate the BM and EM datasets.

- Comparison based on performance: 'Duration'

The approach taken after the analysis of duration and collision, was to then analyse each of the metrics singularly. The box plots below in figures 39, 40 show variance in duration between both groups.

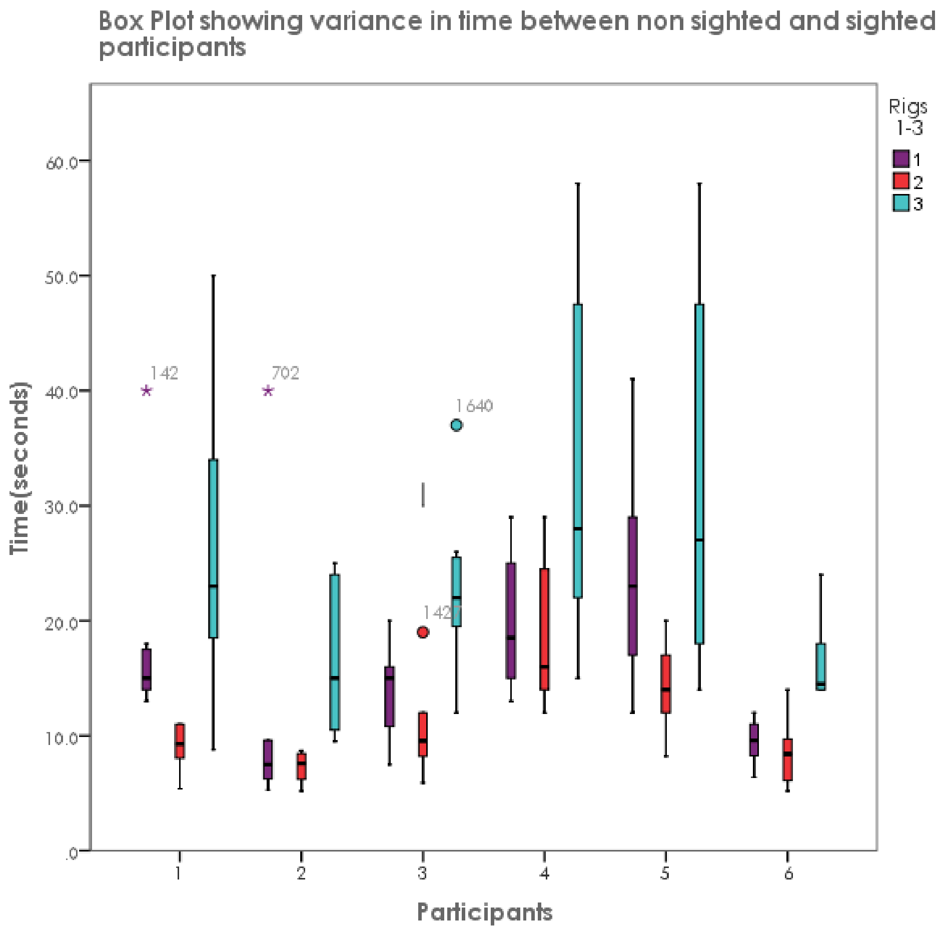


Figure 31 box plot showing the Duration to insert final peg I9 by NS(1-3) and FS (4-6) participants, across three rigs

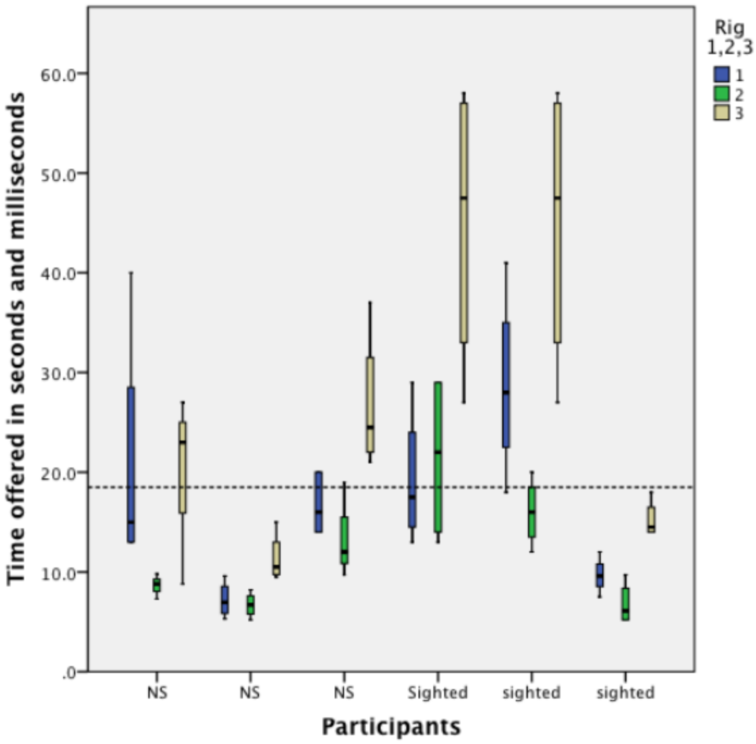


Figure 32 Duration – BM for rigs 1-3 all participants (NS-FS)

In figure *32,* the results show that NS participants, without exception, resulted in a faster time value than FS participants, this can be seen throughout all rigs 1-3, over one testing followed a month later by a retesting.

In figure 33, results are shown against the standard time taken for the completion of the manual Wade's Peg Test (18.5 seconds) *for healthy participants*. From this we can then expect that MH assistance needed to offer enough support to enable *all* participants a lower time record or at least an equal time to that of manual standard peg test for healthy participant time.

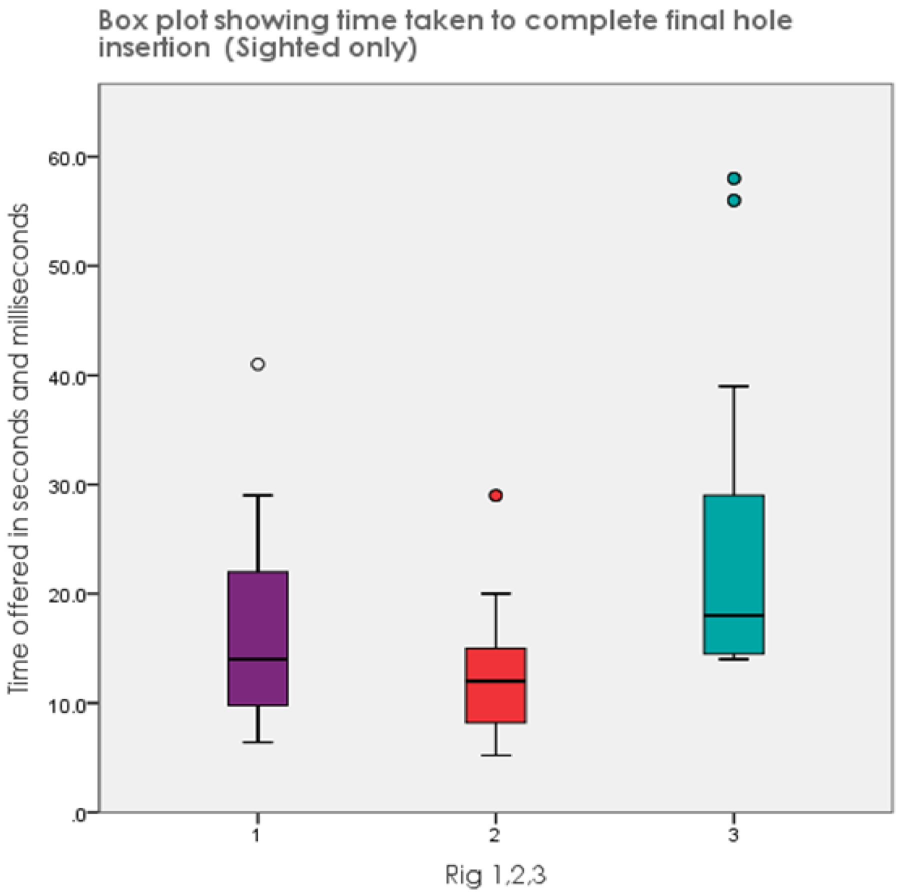


Figure 33 FS rig 1,2, 3

Results shown in fig 33, imply that NS and S participants did complete the MH peg-in-hole test well within the parameters of the standard Wade's 'healthy' participant time for rigs 1 and 2. Rigs 1 and 2 were afforded more haptic force assistance and multimodal cues than rig 3. Therefore, it seems logical to note that rig 3, with little or no virtual haptic force assistance included, shows an increased amount of (secs) time to final hole.

5.15 Results: beginning of the month

Given a standard time taken for completion of the manual test without haptic assistance, recorded as 18.5 seconds for healthy participants. It can be expected that virtual haptic assistance will offer enough support to enable all participants to record a lower time, or at least an equal time to that of manual standard NHPT healthy participant time. Results shown in *fig. 34* imply that NS and FS participants did complete the MH peg test well within the parameters of the standard Wade's 'healthy' participant time for rig 2, where the haptic force assistance and multimodal cues were included. However, rigs 1 and 3, had a variable completion time with respect to the conventional NHPT duration (as shown by dashed line in the plots). The NS participants highlighted, via empirical recordings of rig test 2, that they had no real motor skill or orientation difficulties with this test.

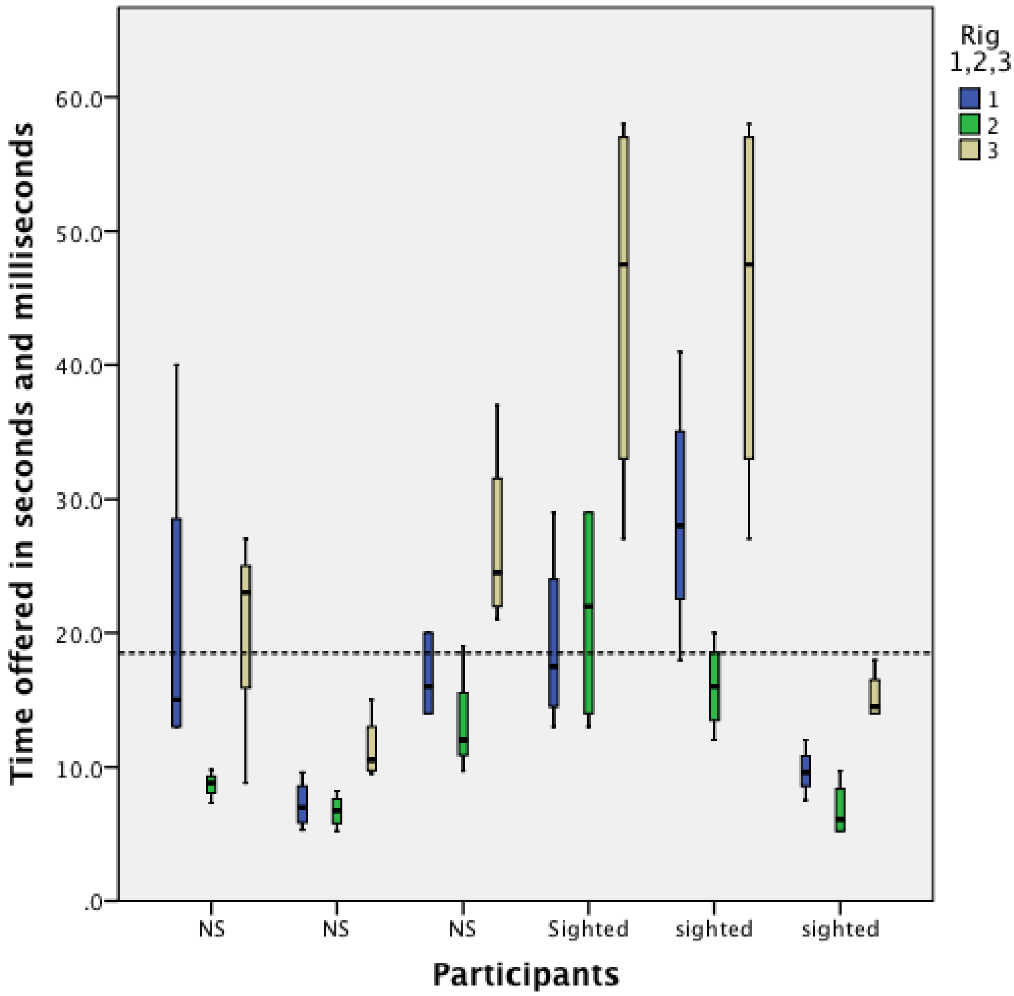


Figure 34 Time - BM for rigs 1-3 all participants (NS-sighted).

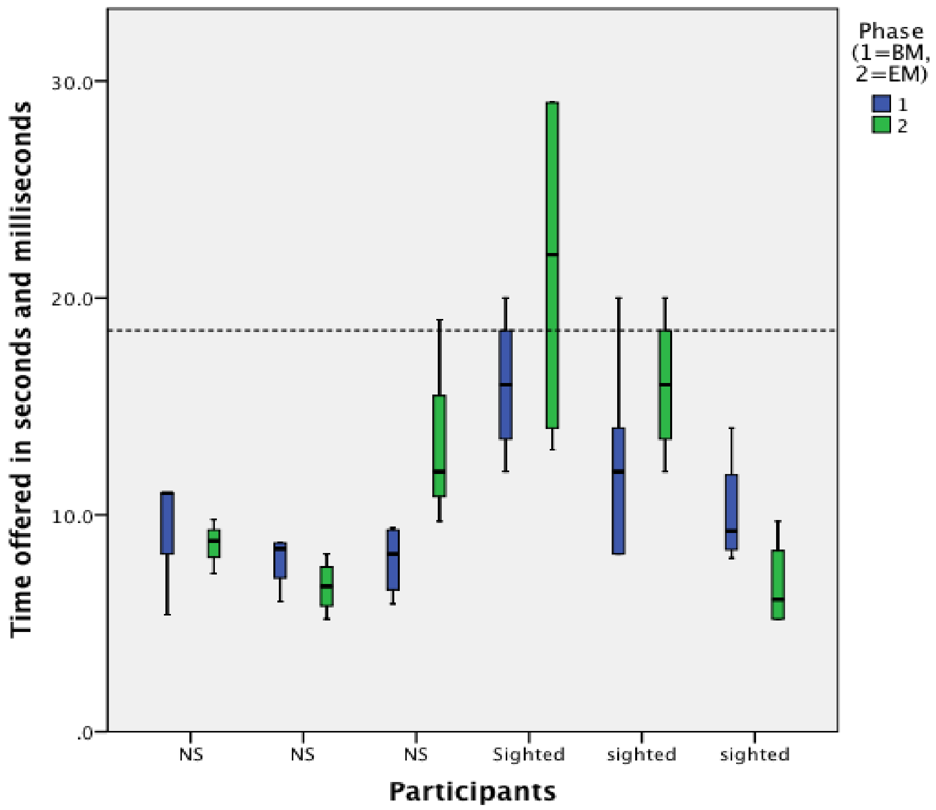


Figure 35 BM/EM comparisons between groups and rigs1-3

An interesting observation made by examining Fig, 35, is that NS participants consistently show smaller variation in performance using the three rigs, compared to the sighted participants. This difference in variance is shown in Fig. 36 time variance between participants comparing BM and EM phases magnified at the EM phase which can indicate a different level of learning, yet further experiments with larger sample size would be needed to draw a more reliable conclusion.

All of the collisions recorded were analyzed and correlated against the time taken to complete each rig test to give an overall efficiency score.

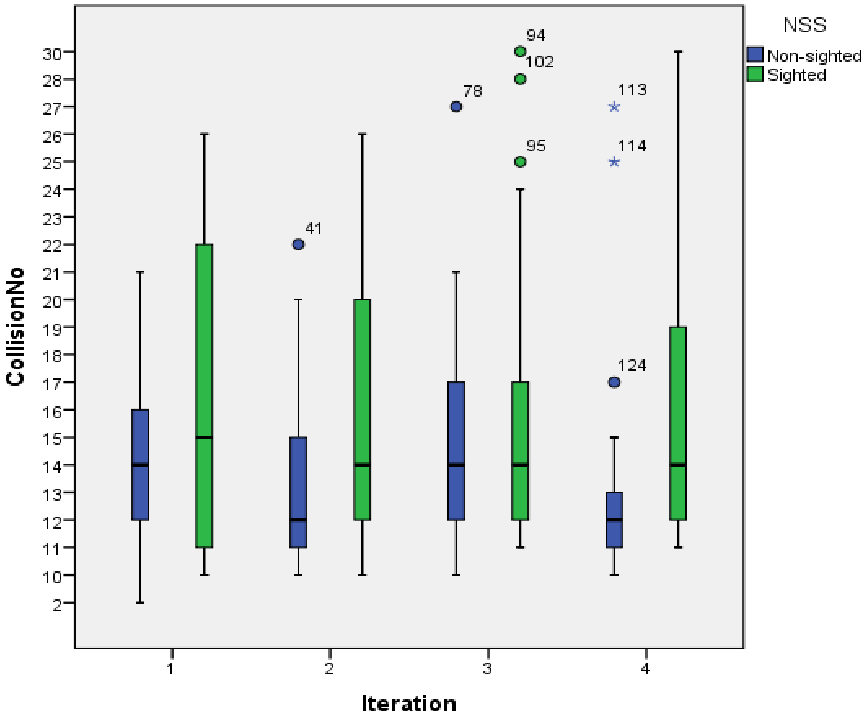


Figure 36 Non-sighted and sighted collisions for rig 1, for four iterations

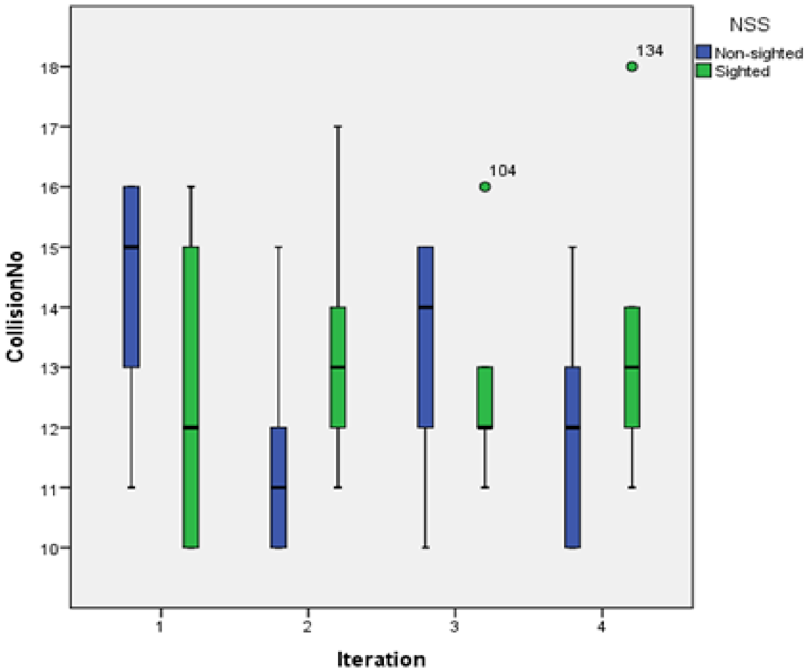


Figure 37 Non-sighted and sighted collision across rig 2,

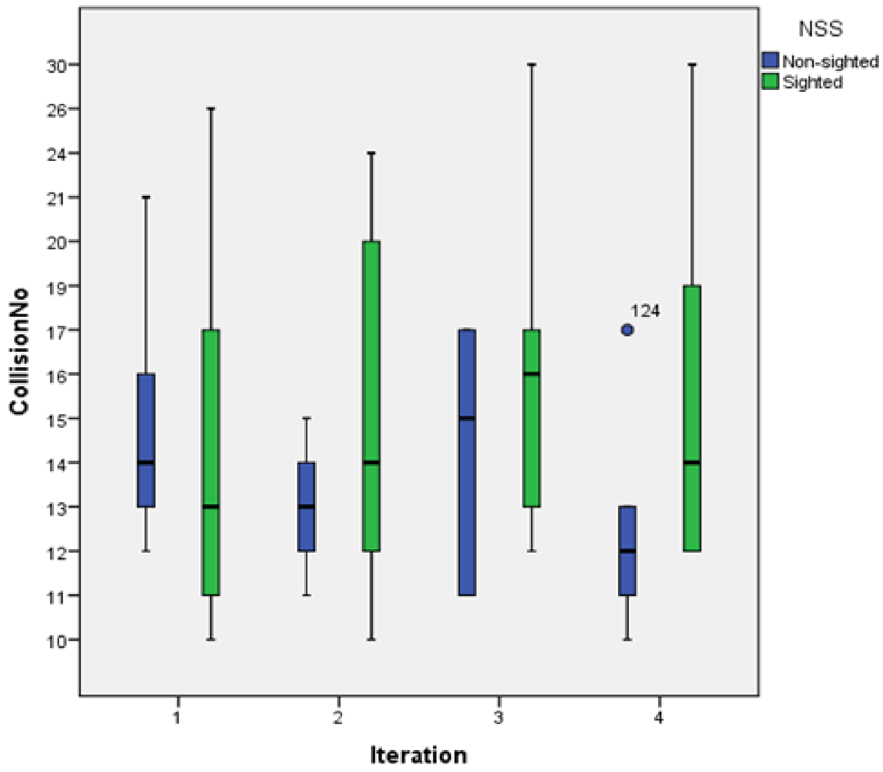


Figure 38 Non-sighted and sighted collisions rig 3 over four iterations

5.16 Discussion

- Deep Dive and Henshaws art-makers

The Deep Dive field study as described above, showed that art-makers preferred to use a single craft tool to work on a specific piece of work rather than a selection of tools, which opposes the industry norms where a plethora of tools are used to fit the process. The Talking-Stick activity highlighted how art-makers use touch to interact with their preferred tool, and how they layout their workstation with tactile cue points to enable easier orientation around their art piece and their workspace. Qualitative data from the PICTIVE peg-in-hole test was designed as a co-design user activity that enabled the layout of the physical tactile version of the peg-in-hole test. The inclusion of art-makers at the early phase of the design and developmental process was complex to arrange and lengthy to complete. In line with other researchers' inclusive study the whole observation process and working with vulnerable sensitive users is never easy, but the perseverance of the process to completion was extremely effective and the results, in this case, aided the on-going studies and the researchers' knowledge of non-sighted individuals in the discipline of crafts and craft making.

The following points were refined and extracted from the Deep-Dive study to utilize in the planning and development of case study 2:

- Singular tool use for many different interactions
- home cue points,
- grip and manual handling technique,
- orientation,
- fixed cue points and
- object manipulation techniques.

5.17 Manual and machine haptic peg-in-hole test summary

The following points offer a detailed discussion of the M and MH modes of the adapted peg-in-hole study,

1. Force feedback: Although most of the NS participants reacted well to the initial steering and haptic forces, this group showed a much better reaction than the FS participants who were confused or inhibited by the guiding forces. It clearly emerged from the qualitative data that NS participants were actually quite used to being manually guided in day to day life for example to a landmark, or starting point. One NS2 offered, "so I will be guided to the holes then? A bit like my support worker does? Oh yeah, that's fine then [sic]." (Bowers, 2013)

2. Audio inclusions: The audio cues allowed the users to have a 'fun' element to the test without being a gimmick, as participants stated that after the rig 1 test they were then listening for the audio cues. All sight impaired participants seemingly enjoyed the countdown stating 'this is fun.' Or 'wow that voice bit was good'. However, some of the non-speech sounds needed to be clearer or louder and using a higher timbre. A collection of different sounds

was also suggested by NS1 participant who found herself listening more and more for a sound cue alongside the guidance, she offered that she was searching for the duality of these senses to cue her to the next hole.

3. The widening of the embedded peg hole - this assistive adjustment was extremely useful, it allowed more single point sensitivity to the users and calmed the users' frustrations which were seen in the previous version of the test, mark 1. Here participants were not enabled to clearly insert the peg into the hole as the hole was simply not wide enough for the user to feel the hole physically and insert the peg at the same time without incurring multiple collisions or a greater time for the whole test.

The qualitative feedback from the MH peg test was very encouraging, and it complemented the quantitative results. It revealed that NS participants liked rig 2, which contained the most assistive affordances. Participants communicated that they felt it was the easiest to work with and they felt that they achieved more in a shorter time. They also enjoyed the audio sounds and they vocalized that in future tests they would appreciate more varied sounds and an even larger increase of force.

To conclude, this study has progressed in proving the RQ1 and is able to state an agreement with the hypothesis, rather than the null hypothesis. The hypothesis agreement and the null hypothesis rejected and this was particularly relevant to the results shown from rig 2, which showed a much better average time per iteration than the Wade's standard manual time to completion (18.5seconds). However, overall the time results for both NS were on par with Wade's standard completion time for a healthy sighted individual.

The next chapter (Chapter 6) outlines, in detail, a qualitative and quantitative report of a second haptic interface (Experiment 2) designed for NS - VI and FS participants. The second study has been designed to offer NS,VI and FS participants access to a more creatively designed test. The chapter discusses the results and shows connections to research questions 2-3.

6 Shape Assembly Test

This chapter will describe and evaluate the formation of the 'Shape Assembly test.' The introduction outlines the context and motivation behind the experiment. It discusses the initial proof of concept working with Associate Lecturers (ALs) employed by the Open University (OU), and outlines the design and structure of the test. Feedback from the proof of concept trials were collated and used to develop the main Shape Assembly Test. Finally the developed (Mark ii) Shape Assembly test is discussed as participant tasks and analysis using a mixed methodologies approach which are presented and discussed.

6.1.1 Introduction

Richard Sennett (Sennett.R., 2010.) communicates his apprehensions, that beyond the PC, designer-makers are losing their ability to develop traditional manual craft-making skills. In Sennett's book 'The Craftsman', he outlines how he believes technology is destroying hand-crafting skills. By using digital making processes, designers can detach from their trained instincts to 'play' to be hands-on with materials and process. Design students are often encouraged to become accustomed to working with materials and processes. To keep an 'open mind' whilst working with their own tactile responses to materials. Many practicing designers often interact with raw materials in a very physical manner. It is common for designers to bend and actively manhandle pliable materials to allow them to better understand their tolerances on the fly, and so they can decide whether or not to utilize them in a prototype creation. Some classically trained designers may agree with the sentiment in Sennett's beliefs. However, CAD technology offers timesaving and technical advantages, so it is often a business decision to work with digital over manual tools.

The experiment reported within this chapter is motivated by the need to offer designers and design students (NS,VI, FS) the chance to engage with virtual haptic tools to use touch to aid assembly of a prototype; by introducing MH tools it is hoped that users will be able to maintain hands-on skills in the digital realm.

6.1.2 Computer aided design and the modelling process

As previously discussed in Chapter 2, CAD and visually-centric graphics tools do present some visual access barriers to NS and VI users. CAD has been known to also offer barriers to less technically driven designers as it can often appear to be a daunting complex technology. Harris and Meyers (Harris L.A.V, 2014)explain that it is common for CAD software to appear complex and technically driven "One of the challenges of technology innovation is that computer graphics software programs, written by software engineers, often come with so many features that the product becomes overwhelming to learn and therefore becomes unworkable." However, Harris et al.,(Harris L.A.V, 2014) assert that in recent years CAD software companies are beginning to incorporate a more user-led approach, resulting in CAD software reflecting a more creative process-led interaction.

6.1.3 Traditional and virtual prototype design

Traditionally the creation of a design 'concept' from 2D drawing to 3D prototype is developed through a series of physical concept prototypes. Prior to the industrial revolution (1700s) crafts makers would typically create low fidelity prototypes often using low cost, low-grade materials for example, clay, off cut wood. The next stages of design concept generation would be to select low fidelity models and recreate them in higher grade materials but at half scale.

During the Industrial Revolution (1760-1840), a clear gap was created between Designer-Makers and the hands-on process of making. A Designer would create a design concept drawing draft and a prototype form. Once a design concept was agreed, the Designer would pass the model to be mass-manufactured. Today Designers' follow variations of a theme of developmental process. The Design Council has framed a standard model which is entitled 'The Double Diamond'(Council, 2018) . The first of the two Diamonds, is shown in (Fig. 28), for the purposes of this study a singular diamond is used to represent the early stages of the design process: the iteration and development procedure of prototyping. Prototyping works with germinal stage modeling or sketch modeling[20]; in low resistant material for example, modeling blue foam. When the first stage of the Double Diamond process uses CAD to develop ideation it could be argued that the process lacks any meaningful level of a hands-on approach, which traditionally has been valued by the 'maker' community.

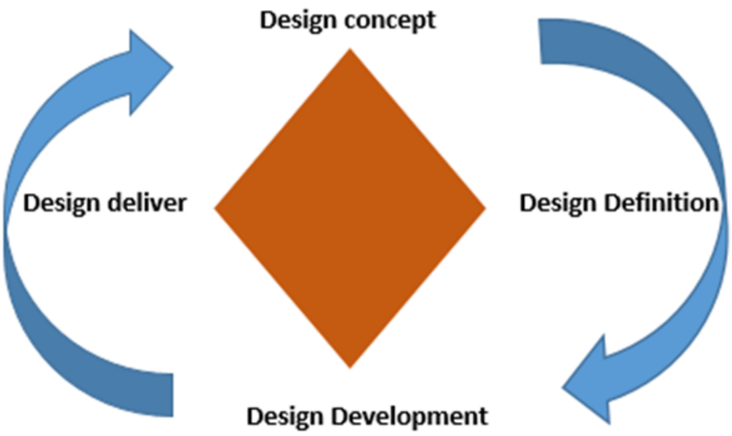


Figure 39 Design Diamond D process adapted from Design Council Diamond D model 2015.

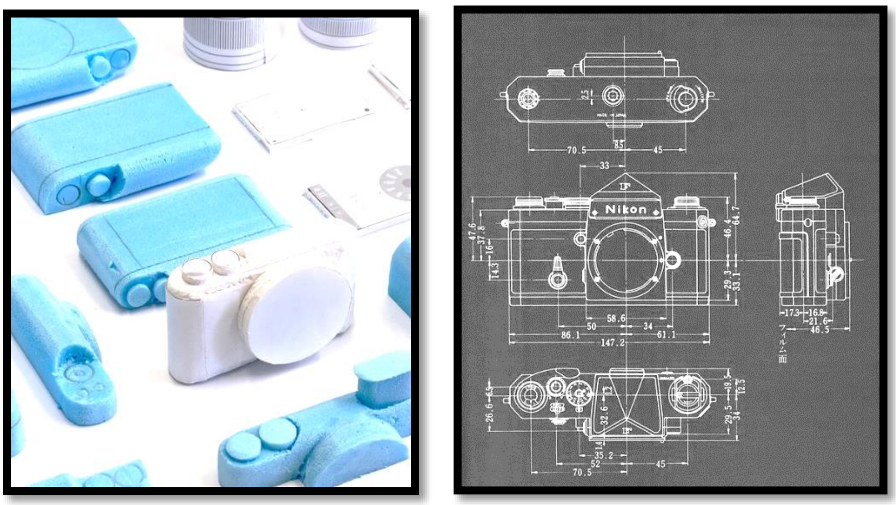


Figure 40 Blue foam prototype (left) and CAD drawings (right) Source: Pinterest Nikon 2017

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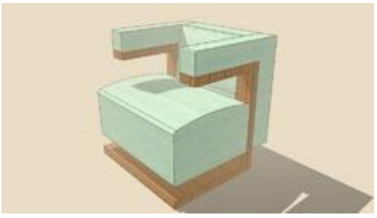
[20] Sketch model is a base starting model which is usually a quick model made from low resistance materials such as paper and card.

6.1.4 Creating a prototype

For reasons of simplicity and brevity a simple geometric based chair was selected to be the basis of the prototype used in the Shape Assembly test. The style and context of the prototype was a simple Bauhaus style chair. The Bauhaus furniture has inspired design students for many years due to its innovations and honesty to materials and form thereby making this historical link it was hoped that OU design students would be equally as inspired to assemble the geometric forms. The selected style of chair, was inspired by Walter Gropius chair (Bauhaus period Circa 1934), and made links back to The Open University 'Design Basics' module.



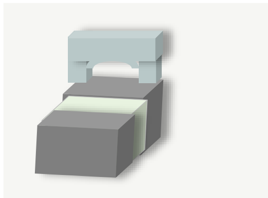


Figure 41 An Example of Walter Gropius block chair

Figure 42 A sketch model of a Bauhaus inspired block chair

Following Gropius's example, the experiment prototype chair was simply designed from four geometric blocks, none of the blocks had interconnecting parts, and all parts of the chair were made of standard readily available (palm sized) geometric blocks. The geometric blocks were selected to be handled by NS, VI participants, in that, they were lightweight, firm but pliable foam rubber; therefore they were comfortable to handle and light enough to pick up if the user had any form of motor skills issues. The shapes were brightly colored and contrasting in tone primarily to make the most of VI residual vision, meaning that the blocks were contrasting in color, or more importantly tone, which is often used to help identify objects (Fulton.S, 2016). The virtual version of the prototype haptic assembly blocks were an exact copy of the manual version.

6.1.5 Haptics and design practice

As previously discussed design, Practice is a uniquely touch-led discipline, where haptic feedback is key to interacting with materials and process to enable design decisions about concept development.

Touch is embedded within most of the elements of the design process:

- The germinal phase- touch is used to create sketch models
- Development phase – touch enables designers to examine and test materials
- The final concept proof phase – designers use the model to allow clients to gain touch interactions with the model.

Much like Scali et al., (Scali.S., 2013), this study has also identified the 'germinal phase' of the design process as a key stage to exploit haptic interactions. The germinal phase is when the designers' concepts are more organic and there is a flow between drafts on paper, models and reflective cognitive processing, this is the ideal process to adopt in order to maintain creative thinking. Often, within this phase, designers externalize their ideas through multi-media and model assembly, which ultimately aids the designers' ideation process. There is a fluidity between mind and touch, tactile interactions would be useful at this time as it is where the Designer literally draws out ideas, physically trialing the concepts haptically, then returning to an autonomous reflective mode. Occasionally, designers may just assemble a Marquette[21] /prototype without any drawn element, then re-draw the Marquette in varied extended formats to extend the forms of the design concept. Designers may return to Marquette model and create alternative versions or alter the original Marquette, the fluidity between ideas and modeling is important to retain at the germinal phase, as it allows the designer to maintain a sense of freedom of thinking.

For this study the germinal stage is used as a vehicle to create a haptic model assembly interface. The assembly of pieces of the model at the germinal stage would usually be a rapid dynamic process; often designers

[21] A Marquette is another common term for a low fidelity model, although the traditional use of the term Marquette was used by carpenters or craft makers, and prototype was the term used in industrial design.

limit themselves to 3-5 minute model assemblies. The speed of assembly retains the impulse and creative notion of the model concept and allows the Designer to manufacture a series of models for a later more refined selection. Therefore, this study sets an acceptable maximum industry standard time (5 minutes) to the model assembly test.

6.1.6 Developing the design of the 'Shape assembly test' interface

The reason for selecting the germinal stage of design (early stages) was to allow design students access to a 'hands-on' virtual modeling technique from the early stages of the Diamond D' process. The 3D block mesh was created from a 3D scan of the physical blocks. The 3D scanned 'nets' were transferred into the virtual 3D environment, where the nets were colored and smoothed using the haptic 'Openware' programme, 'SOFA Unity'. The overall design and layout of the haptic rendered environment was designed using a standard graphics package. The following flow diagram (Figure 41) depicts the designing process of the haptic interface:

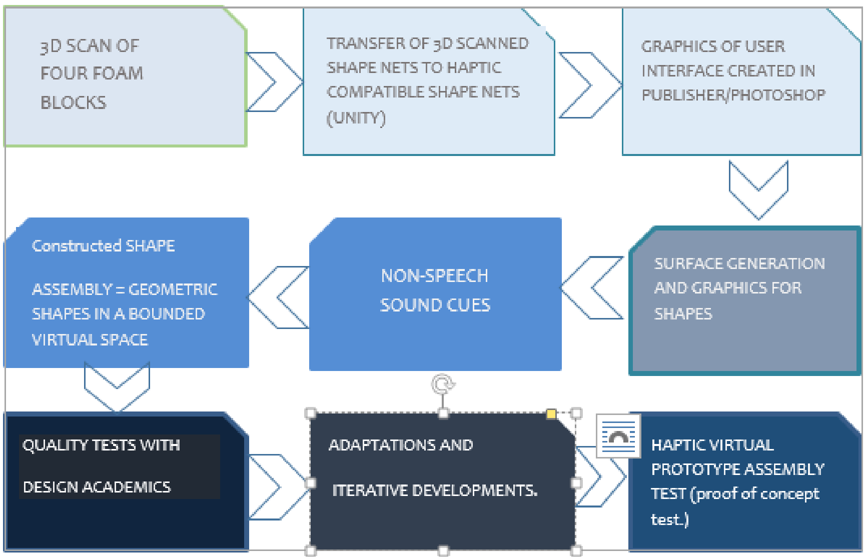


Figure 43 Flow diagram of haptic interface design

6.1.7 Pilot test procedures and outcomes

As outlined in the Chapter 4, Methodology, a pilot test was created to trial the concept of the Prototype Shape Assembly test (beta version). Three design academics employed with the Open University were invited to trial the MH interface and to use a simple think-aloud protocol, followed by an evaluation questionnaire. The aims and objectives for this test were to gather points for development from the academics, and their brief was to offer evaluations with FS and NS, VI students' use of the MH interface in mind.

Each academic was initially requested to first assemble the prototype model of the chair (shown in Figure 42) in M and MH modes; in MH users worked with the selected haptic device - the Geomagic Touch. The three academics all gave a detailed account of their experience through the use of the Think-Aloud technique, and through post-test evaluations.

Once accustomed to the space and using the probe, participants were keen to explore all the walls and ceilings of the space using the probe, and they were surprised when the environment responded by offering the user the same tactile feedback as would be expected in a real-world context, "Can I feel [sic] the walls and floor as a resistance?" (OU Participant AL2) "I am going to try and pick this up now…oh it's moving…" (OU Participant AL2)

Once participants had probed the environment fully, they were then more confident to interact with the 3D shaped blocks centered on the floor of the space. Two of the participants felt that they needed to draw on the facilitator to remind them of what to press and how to react, and felt that they had to pause to collect their thoughts before acting on the instructions as they seemed to be tentative about over forceful use of the probe and the virtual environment. This disappeared once the participants had been using the tool for 10 mins or more, and the users were observed to relax back in their seat and not ask so many questions.

"I am glad that I have the guidance verbally, or even just someone there, as I don't want to break it…" (OU Participant AL1)

One of the participants offered in the test think-aloud dialogue that she always usually needed a break with motor skills work due to a personal injury, but she felt ok with the stylus and felt the force actually helped her to move smoothly. All the participants stated how they felt they were confident in the knowledge that the environment was solid and how the 3D shapes' weight aided in their relation to the VR from their understanding from the real world. All three participants felt that they were intrigued to change the camera view of the probe in connection with the 3D environment, but they also felt it distracted them after a short time. Observations showed that when each user changed the camera angle, they seemed to move nearer to the screen, and they angled their heads in relation to the camera view. All participants reported that by using the probe they felt physically drawn and connected to the visual environment in a manner that made them feel more 'present' in the environment, although this was only reflected and commented on after the pilot trial.

Given all of the feedback and qualitative evaluations from the pilot test, there were some areas highlighted to revisit and develop further to allow for a more user-friendly experience, shown in subsection. However the benefits of using the haptic interface were apparent from the Associate Lecturer feedback,

> "I came home really enthused by the idea, it certainly seems to be the way forward. So exciting that we have been able to get computer technology this far within Education. The opportunities as a tool for design for distance learners are endless as far as I can see." (OU Participant AL2, 2017)

> "I believe that haptics will be at the forefront of developments in technology that will have a big impact on societies future and I can see this being used alongside other developing fields within design and technology etc., such as 3D printing, fabrics that integrate digital technology within fashion, textiles that are sustainable and building materials that look at being low impact. (OU Participant AL3, 2017)

> "I find this fascinating and an area that it stimulates my own creative thinking." (OU Participant AL1, 2017)

The range of Associate Lecturer comments from the pilot test offer strong words of endorsement, which was encouraging. As critical parts of the teacher student contact, Associate Lecturer colleagues hold a great depth of experience of student needs and a deep understanding of the role of VR embedded in The Open University's Virtual Learning Environment (VLE). Comments of particular interest was from AL1 who made reference to the haptic interface stimulating her creative thinking, this is a particularly useful comment as it appeared, for this individual, to connect haptics and the movement of objects in virtual space with creative thoughts, this was an encouraging reaction to the first use of the haptics tool.

6.1.8 Pilot test outcomes

The results of the test time, showed the haptic interface was above the design industry norm' time (5 minutes) to assemble a sketch model *(see table 12).* The comments from the academics through Think-Aloud and post-trial evaluations offered that the interface did require more development, as there were some inclusive and technical / usability issues revealed in the beta tests Mark 1 version.

Table 14 Quantitative results Pilot test demographics

Staff No.	Gender	Dominant hand	Duration (Mins)	Collisions
S1	F	R	7	4
S2	F	R	8	3
S3	F	L	9	5
		(M±SD)	8±1	4±1

The following reveal the Pilot Test developmental issues:

- **Prototype Process mimicry** - there should presented to the student in a similar format to that of a CAD screen layout, which would allow the users a known layout, making orientation easier. The users were told that we were not haptically rendering the structural layout of the screen, and non-sighted students would not be able to recognize the visual difference between CAD window and the haptic rendered window. However, the comments were taken onboard and the layout of the screen was simplified.

- **Prototype Process mimicry** – to mimic the physical version of the manual prototype process including aspects of the 360 degrees view of the prototype object. It is common for designers to keep moving the prototype whilst working with it to enable them to see the forms and shapes as the model is built. This aspect was challenging as the foundation block needed to be fixed to the 'floor' of the bounded space so non-sighted participants would have a fixed firm starting point from which to begin assembly. However, a viewing button was offered to visually impaired and sighted participants in case they wished to view other facets of the model.

- **Agility, speed** –Users felt that although they could feel the freedom to move around all areas of the bounded space and shapes within the space, they felt that technical difficulties such as the 'jitter' issue had affected their performance in completing the test within the given time.

- **Multimodality** – Although users appreciated that the system was set up to be inclusive, they felt that small adjustments, such as screen color, could be an issue for visually impaired students, who in computer labs were often seen to alter the contrast, or color range of the objects on-screen to suit their particular form of visual impairment. The final multimodal issue was the non-speech ping sound was too high pitched, and it was felt that a calmer non-speech sound should be adopted as the high pitch ping seemed to panic the users and make them anxious. A softer alert sound was found and used within the main haptic test.

6.1.9 Main, Shape Assembly test

- Participants

The main Shape Assembly test enrolled twenty participants, ten were sighted and the remaining ten were registered as non-sighted or sight impaired. In the non-sighted/sight impaired group there were five females and five males, none of the non-sighted group reported any other motor or sensory impairments at the time of the test. The non-sighted/sight impaired participants were recruited from the Engineer and Innovation school in the department of STEM at the Open University.

The sighted sample group was made up of seven males and three females, none of the group wore spectacles and none of the group reported any health issues, motor impairments at the time of the test. The sighted group sample were mostly studying in the school of Engineering and Innovation, with two from the Faculty of Arts and Social Sciences (FASS) but registered to Design modules at the time of the testing.

All twenty participants had good knowledge of computer aided design (CAD) software used to design product design solutions. However, only 45% had highly-experienced computer-based knowledge of prototyping, and used freeware and licensed software systems e.g. Google Sketch-up, Blender, Autocad. None of the participants had any prior experience of using any form of haptic device such as the selected device - Geomagic Touch device.

Table 15 Participant Demographics – sight acuity, gender, number, dominant hand and age

Participants	No.	Dominant hand (L/R)	Age (Years)
Males (NS,VI)	5	2/3	42 ±22.8 -sd
Females (NS,VI)	5	1/4	47 ±14.9-sd
Males (FS)	7	0/7	33 ± 13.1-sd
Females (FS)	3	1/2	29.6 ± 5.5-sd
Total	20	20	37.9± 8- sd

6.1.10Test Design (Mark i and ii versions)

The Shape Assembly Test used mixed media concurrent triangulation approach, consisting of qualitative and quantitative data collated concurrently and then the two data collections were compared to determine whether the data converged, held differences or a combination of the two. The data was measured as a between-subject data, and quantitative metrics applied were shown as time (titled - duration) time was shown from the beginning of the test to full assembly and shut down of the virtual environment. The second metric used was collision (titled as nCollisions). The collision metric was used when a participant collided with a static (non-active) shape, or a shape that had already been assembled.

Qualitative methods were selected to gather data from Think-Aloud technique which ran throughout the whole test M and MH modes. The test also included a post-test Likert questionnaire, sent to all participants on the evening of their test day to complete and send back via a closed password protected submission box. All qualitative feedback was analyzed via NVivo v.21 software (themes and node construction is outlined in greater detail in Chapter 4 and, all raw data can be **seen in Appendix B**).

6.2 Haptic Stimulus

- Virtual and manual Shape Assembly Test descriptors are presented below

a) **Manual (M) test:** At the beginning of M test, 2 block shapes were set 1 x acted (fixed) foundation (yellow) cuboid, 2 x red cuboids set slightly apart from the foundation block. The M test offered user one fixed block and one in front of the fixed block. Two further blocks were placed in a wooden box, when all the blocks were assembled the chair prototype would be complete.

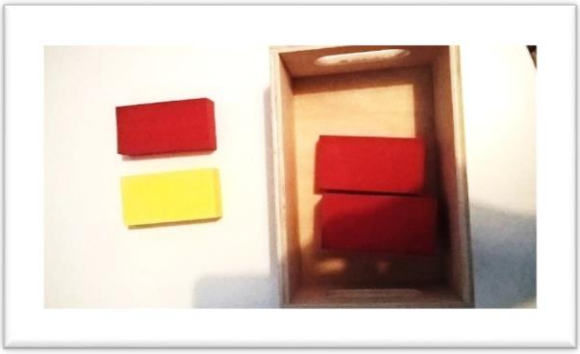


Figure 44 MP Prototype Blocks (authors own)

Machine haptic (MH) test: The on-screen interface showed *two blocks dimensions - 25 x 4 x 23mm* foam rubber *(simulated)* shapes. One was fixed to the floor of a bounded environment (yellow), and a second block (red block) was located in front of the fixed block facing the participant 2 further red blocks were held away from the first two shapes. Participants could 'call' for their next block by hitting the space bar for it to drop.

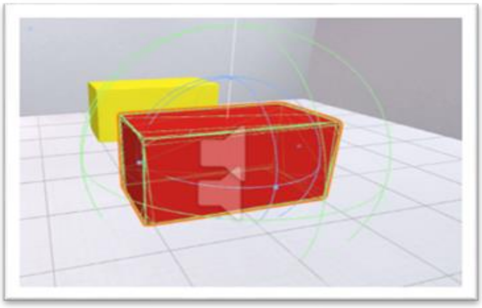


Figure 45 VP prototype blocks (author's own)

All participants were requested to complete each M/MH prototype assembly tasks within 5 mins the 'industry norm' for sketch prototype construction. If the participants went over the allotted 5 minutes, in either mode, they would be stopped, in MH mode, the system would close down.

6.2.1 Test apparatus

The machine haptic stimulus was presented to all twenty participants via the Geomagic Touch device, (specification for this device is shown in table 4). The Geomagic Touch device was run on a Windows PC 1.7 GHz base frequency, up to 3.3 GHz with Intel and displayed on a 68.58 cm (27") monitor *(anti-glare)*.

The manual haptic stimulus was in the form of 4x (palm sized) geometric foam shapes, 4x 25 x 4 x 23mm (palm sized) foam rubber shapes (1x arch 3x cuboids). Also used in the manual trial was a digital stopwatch and laptop to record manual data. A (HD) Flip video camera (8GB) which was mounted on a tri-stand to record all of the participants M and MH interactions was used to record all user interactions with both M and MH conditions and apparatus).

6.2.2 Procedure

For the pilot test and the main Shape Assembly Test all participants were seated in front of a haptic device which was mounted on a desktop in front of the participant. Initially the researcher described the two haptic tests, and asked all participants to complete a brief pre-trial test before commencing with the main haptic assembly test.

For both the M and MH test Non-sighted/sight impaired participants were requested to sit comfortably with the haptic device in front of them but so it was at a comfortable reachable distance. Participants were asked to sit one seated position so that they didn't have to move suddenly during the brief testing period. Non-sighted participants were informed that they would initially be guided to a fixed block, they would then have to pick-up and stack the block in front of the fixed block. Preceding blocks would then be called upon by pressing the space bar, and they would drop down to the front of the stacked blocks. The participant then needed to use the haptic device to assemble the two remaining (red) blocks to complete the test. Once the final block was in place the interface would close and deliver a final time (duration) taken to completion.

For the manual haptic test, participants were instructed that the start layout was set, and that they should place the first yellow block onto the (red) base block and then collect the spare two geometric shapes from the wooden box to complete the Bauhaus styled chair prototype.

6.3 Pilot test (Mark i)

The pilot test, was designed to assess whether a haptic interface could support students' prototype assembly within the early phase of development, which was aligned with Scali et al., whose evaluations offered that a haptic device would be effective when used within the early phase of design process, as it would support a high level of hands-on process (Scali et al., 2013) to aid modeling manipulations. Evans et al., also endorsed that designers are a 'touchy-feely' lot (Mark Evans, 2005). The Geomagic Touch device was selected to assist users to assemble a 3D sketch prototype model, within an accepted industry time of 5 minutes. A mixed method approach to the research process was adopted to further understand the efficacy of technology and evaluative user feedback. The initial pilot test used questionnaires and Think-Aloud data, to collate qualitative data from three design academics who were selected to inform on the pedagogic value of the haptic interface, as well as their thoughts and feedback on the introduction of such a device to extend non-sighted students interactions within the suite of design modules offered by The Open University. The results from the tests above revealed encouraging feedback from all the design academics, who commented on various aspects of the design and implementation of haptics to the design prototype process. They were enthusiastic about the force guidance to virtual objects and the depth that the devices six degrees of freedom allowed.

They commented that the auditory feedback, via non-speech and alert sounds, were well placed and did grab their attention when used in conjunction with augmented touch. However, they felt that the pilot version of the interface could be developed further before offering it to guide non-sighted users. They felt that the force could be increased, the incidents of jitter of the shapes when being assembled should be fixed and that there should be additional non-speech sounds to guide all aspects of the assembly; they also suggested a count-down voice cue to alert users of the starting point. The important part of the post-trial discussion with design academics was that they fully endorsed the importance of introducing touch-augmented tools to assist non-sighted and visually impaired design students. The general consensus was that machine haptics would offer a novel but useful sensory interactive tool, which would then feed into the 'Open' access policy allowing more visually disabled students access to a new form of digital design process. To enforce the level of positivity for the introduction of haptics to The Open University, Participant 1 stated "to engage with 3D models brings an entirely different dimension to the student's design concept thinking. Your interface offers students the simulation of 3D designed models in a virtual world… This tool has so much more potential for non-sighted learners who, may now, engage with models through touch." (Appendix B)

6.3.1 Pilot test limitations and additions

The limitations of the haptic interface were evaluated by academics revealing that the mark 1 version of the interface had some development and technical issues. The issues resulted in all three participants tasks were drawn out to longer durations of task than first expected (average - 7 minutes) to complete the pilot test. The results also showed that the collisions rate was higher than expected (average 5 collisions). Overall, the results of the pilot test showed that although users felt immersed in the interface, the technical issues was interrupting their concentration and their 'belief' in the tool's ability to fulfil the shape assembly task. As a result of this feedback all of the salient limitations were listed and a mark 2 version of the interface was developed and this version was used as the main test interface.

Although the participants evaluated the Mark i, interface held great potential, they also suggested that future studies should explore the potential of adding model manipulation functions to the interface. They stated that this would aid the design student to develop their sketch model further e.g. functions which would allow students to change the surface texture, scale, and color of their prototype.

6.4 Shape Assembly Test (Mark ii)

- Pretrial test.

Prior to the Shape Assembly Test (Mark ii v) all participants were requested to complete a pre-trial test prior to the main assembly trial. The pre-trail test was classified as training for all users and was designed to allow users to 'feel' the force feedback by using the haptic device to complete a simple task. The task was known as the 'pick up and put down' task *(Fig.56)* participants were asked to 'pick up' a 3D cube and put it down, guided by force feedback to the 'x' and '+' marked cues on the floor of the environment.

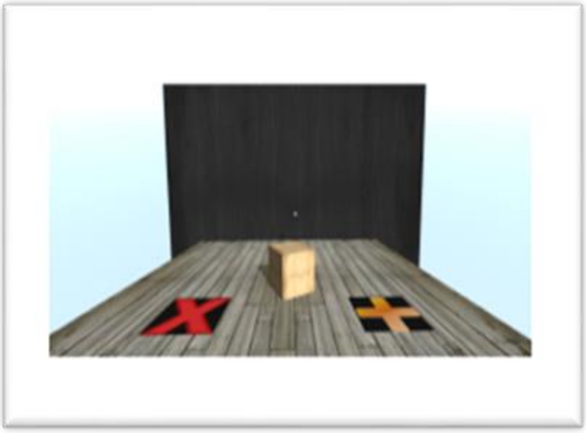


Figure 46 Preliminary training 'pick up and put down task, screenshot Source: author's own

As discussed prior to the test a sample chair prototype was designed by the researcher *(Fig 42),* the chair was 3D scanned and 3D printed to create a physical replica model of the chair. This 3D printed model was generated for the NS, VI participants to feel to understand the shape of the chair that they were to assemble; this was of course in lieu of the individual being able to see the prototype of the chair. The 3D chair was presented to each participant prior to the both MP and VP assembly tasks. All participants were also shown how to use two movements to connect the module shapes of the chair on-screen and physically. The users were shown a push/pull technique, users were requested to simply pushing the blocks shapes together with a single digit in M mode and in MH mode using the single point of stylus, they were asked to push the blocks in the mid-lower point of the shapes and to push the blocks along the floor of the environment until they heard them lock together. The following descriptors describe the test protocols, conditions and assistive adaptations added to the VP interface.

6.5 Qualitative results

Prior to the Shape Assembly Test NS, VI users, in their post-trial notes, highlighted that previously their interactions with visually centric 3D objects presented via GUI, felt limiting to their perceptions of the shapes and their connections to each other. The feedback results showed that 80% of the NS, VI group showed an agreement that they would not or could not have considered being able to access on-screen objects/environments for teaching and learning purposes within their registration period at the Open University. The increase in multimodal/haptic engagement with the virtual space was agreed by 80% of all participants, that it has allowed a clearer immersion to primary interactions with virtual objects on-screen and to fully interrogate them in a more rigorous manner. The results showed that participants felt that they were surprised at how easy the device was to hold and to interact with objects on-screen, but moreover NS, VI participants commented on how 'real' the simulated foam blocks felt, in comparison to real-world foam blocks used in the manual test. They went on to state that the realness added to their mental mapping of the materials of the shape as well as the look and feel of the prototype model as they were assembling it. Finally non-sighted participants were eager to use the haptic device again and volunteered to be involved in future works, and one particular congenitally non-sighted participant stated that they felt, prior to the test, that the experience of using a haptic device would be highly intricate, complex and unintuitive for someone in their later years, yet it was actually the opposite; it was simple and easy to control and he would endorse using it again to other students with similar conditions.

Using the concurrent triangulation mixed method approach the First level data translation was for qualitative data. Using NVivo 21 it was revealed that the most commonly repeated word used by participants throughout the MH test was 'easy'. The most common word to come from the Think-Aloud technique analysis was 'understandable' and 'interesting'. Further refined thematic analysis was undertaken, analyzing post-trial qualitative feedback. Themed headers used were, usability, understanding, and fit for purpose. The theme of usability was the most common theme to trigger user feedback. In particular, the NS group participants wanted to record their appreciation at being able to gain access to a technology-enhanced learning tool which could aid their computer access via an innate sensory interaction.

- **Usability/Understanding**

There was a consensus of agreement for 60% of the NS, VI participants that the haptic device was easier to control than previously expected. There was also an agreement that they could understand the potential of the haptic tool/interface within engineering and design for prototyping and they understood the affordances of haptics could link to offering more access to graphical design software for NS and VI students**.**

Participant NS9 (9, 2017)stated:

> "It was satisfying accomplishing something which I had previously thought impossible/very difficult in a relatively easy manner."

He went on to say:

> "Moving from a mental picture to actually creating a prototype was satisfying. Without the interface I can't conceive how the task could be accomplished on my own. Only [sic] other alternative would have been a sighted assistant to do all the work."

- **Usability/Understanding**

There was also a shared agreement between NS,VI and FS of how easy it was to use the haptic device and interface interaction by both group. However, one participant NS8 **(shown Appendix B)** (NS8, 2017) indi-cated an innate need to use both hands to interact with the 3D objects. He stated:

> "It was also somewhat confusing at the cognitive level, that while holding the pen in the right hand and clearly feeling a virtual wall, the left hand did not feel anything."

Although the walls of the bounded environment were cued to offer users feedback when touched occasionally if the users did not place enough pressure on the walls then the feedback was slightly less effective than others who gained more feedback due to the pressure applied to the virtual plane. This could explain why NS8 couldn't always feel the feedback from the 'virtual wall'.

FS group showed that there was an agreement on how the haptics offered more sensitive and fidelity of touch feedback than initially expected, participant FS5 (5, 2017)commented:

> "… the device was easy to hold and intuitive to use. I was impressed by the feel of the boundaries in the APP when converted to resistance in the device. Being able to feel the weight of the object was also a pleasant surprise."

It was encouraging to note that participants were able to feel the force feedback, translated as weight in the prototype forms offered from FS5, but the device stylus was according to manufacturer standards and nothing to do with this particular test

6.6 Quantitative results: Time (Duration)

The following analyses the time termed here as *duration*, and *Collisions, here termed as NCollisions for both groups* during test performance. Initially, both parameters were tested for 'normality' which resulted in an insignificant difference between the parameters, as a result of this the Mann-Whitney U test was selected over the use of the Analysis of Variance test (ANOVA).

Table 16 Mann-Whitney U, mode time comparison of NS and S participants Shape Assembly Test

Ranks

	Group	N	Mean Rank	Sum of Ranks
Duration	Sighted	10	10.20	102.00
	Non-sighted	10	10.80	108.00
	Total	20		

Test Statistics[a]

	Duration
Mann-Whitney U	47.000
Wilcoxon W	102.000
Z	-.227
Asymp. Sig. (2-tailed)	.820
Exact Sig. [2*(1-tailed Sig.)]	.853[b]

Mann Whitney U test calculated ranks from both groups' shown in table 14. Table 14 represents **duration** and calculated using software SPSS v21. The sum of ranks show 102 sighted and 108 non-sighted these ranks are very close, indicating that there was little statistical difference between-groups for duration. The conclusion for the initial statistical test was that we do not reject the null hypothesis due to the 100 > 47. Therefore we can stated that the between- group 'duration' do not differ significantly.

Table 17 Mann-Whitney U test results

Test	• Z result	• P value
Both groups, MH, Duration	• -2.27	• 0.82
Both groups, MH , NCollision	• -1.43	• 0.52
NS Duration VP and MP	• -1.06	• 0.28
FS Duration VP and MP	• -1.37	• 0.17

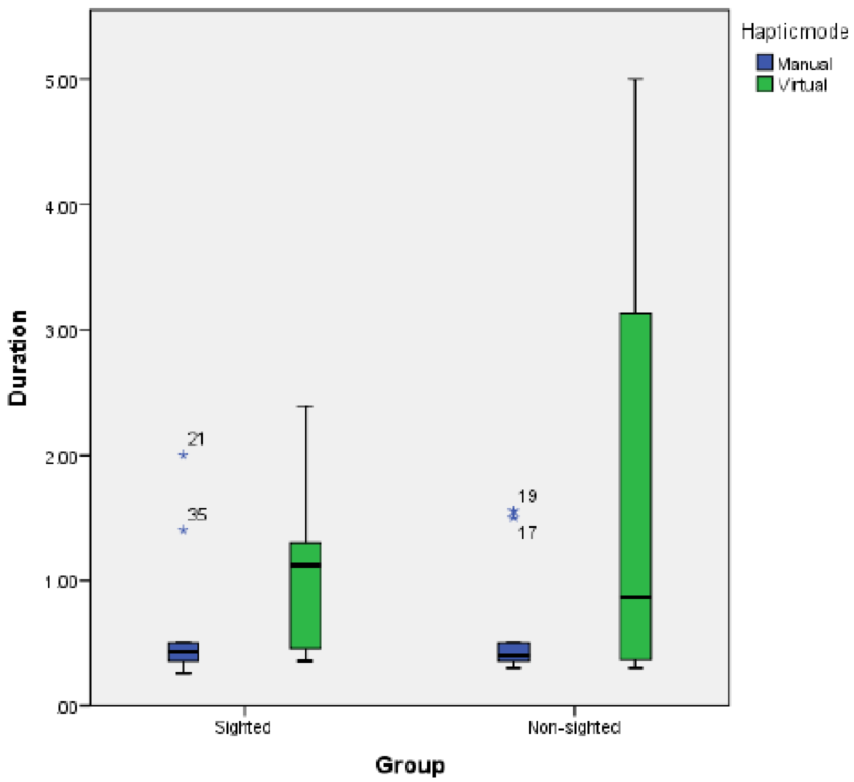


Figure 47 Box Plot Duration of shape Assembly test for both groups

Table 17 reveals the collated results for duration and collision again using the Mann-Whitney U tests, to analyze differencing between-groups and duration across both modes. From this it was clear that there was no statistical differencing for the duration metric tested in between-groups and between-modes, again no difference was revealed for between-modes and between-groups, as shown by the p values and Z values.

The box plot shown below, revealed that in the M mode condition, the between-group results again showed very little difference in duration to complete the prototype task. Sample data for MH (shown on box plot as virtual) between-groups analysis showed contextually a small difference of time, with the longest duration shown as an outlier (NS).

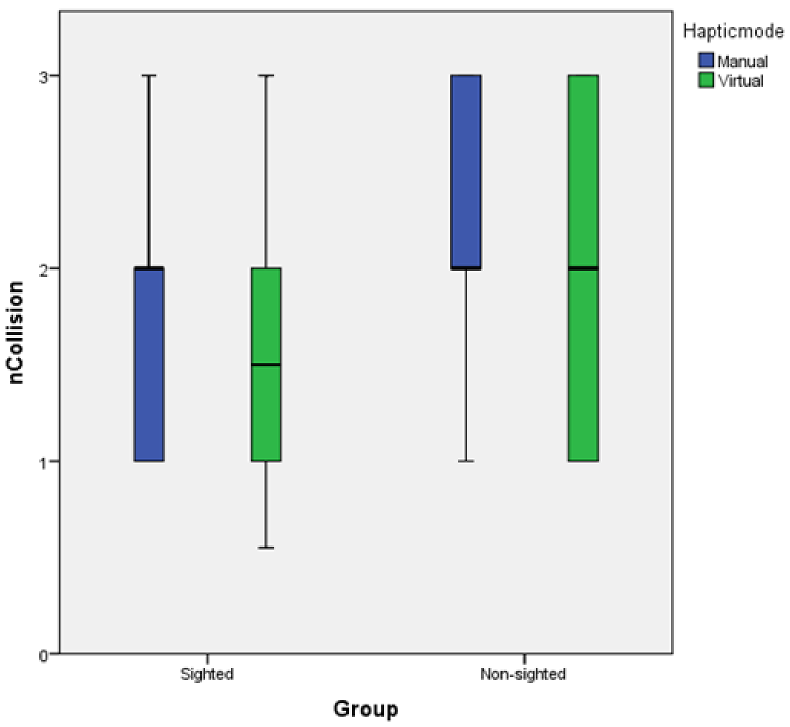


Figure 48 Box plot showing the number of collisions for both groups, in both M and MH modes.

6.7 Quantitative results: collisions

The numbers of collisions were examined; a collision was defined as a single block colliding with another but not connecting to bond the blocks together, during the process of assembling the prototype. For the M/MH modes, recordings of each participant's tasks were created, coded and analyzed by two raters; the second rater's sample size was calculated at *80% of the* coding sample to observe collisions. Cohens Kappa (*k*) was performed to achieve a moderate agreement result *(0.50),* showing that between two inter-raters, there was a moderate agreement of the collisions made. Similarly to duration, the numbers of collisions were analyzed using a non-parametric testing (Mann-Whitney U test).

6.8 Discussion, Shape Assembly test

This chapter has reported on the Shape Assembly test which was shown in manual and machine haptic conditions. The assembly test was selected as it exploited the kinesthetic nature of touch-led interactions used in model making. The test also acknowledged the touch-led nature of the non-sighted participants and in response to this facilitated them with a touch-led approach which replaced the sight-led approach to prototype assembly which had previously been only presented through visually led computer aided design (CAD) format by The Open University.

- Discussions – Duration

As shown in the results the NS, VI group took longer to complete the assembly task than the S group. However, both the NS, VI and S groups were able to achieve a task completion time which was well within the industry accepted standard time, and with only a short period of training (10 mins) prior to the testing session. This means that the haptic had afforded sufficient assistance in achieving a time which was better than the accepted industry assembly time. This variation in time between manual and machine haptics is thought to be due to the learning curve of using the machine haptic device for a minimal period and future work can consider additional exposure sessions, while observing the variation of haptic conditions.

- Discussion – Collision

Prior to the experiment both participant groups were trained in the exact push technique required, meaning that participants were asked to push blocks together with one digit during the MP or the end of the stylus during the VP session. The push action was selected over a 'pick up and put down' action to connect prototype blocks due to the simplicity and brevity of the push action. All participants appeared to easily understand the 'push technique' and successfully used this throughout the assembly tasks.

The collision data showed that statistically there was very little difference between both groups and between manual and machine haptic conditions. It is hypothesized that, in part, this is due to using a 'push' action shown in Fig. 49. The push action was designed to minimize block collisions, and speed up block alignment. By designing an alignment of additional blocks to the foundation block participants could then use a single push action to connect the shapes. This action lessened the risk that the new block may collide with other blocks, in error, whilst being placed. Added to this, non-sighted and visually impaired users would find it difficult to know where to locate the foundation block in order to assemble the blocks, but by designing the blocks so they dropped down in line with the foundation block, non-sighted users merely needed to push the blocks together in one swift movement.

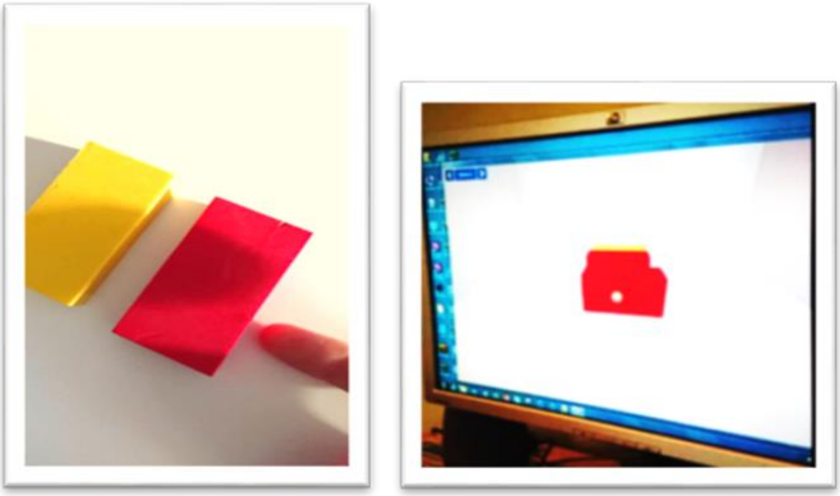


Figure 49 left Manual prototype apparatus showing push action right Machine haptic screen showing push action assimilated

This study was the first of its type at the Open University, but now it is expected that more like-minded haptic trials will be reviewed by the Open University. The study has shown qualitatively that NS, VI participants specifically found the trials easy to operate, that they were inspired and, moreover, interested in the use of haptics to augment touch and to enhance the interactions of the design process.

6.9 Summary

This chapter's sections have reported on an action based case study using manual and machine modalities. In the first instance a haptic pilot test working with three design academics was discussed followed by a report on the case study of The Shape Assembly test, working with twenty non-sighted, visually impaired and sighted participants using manual and machine modalities.

The aim of The Shape Assembly test was to discover whether a MH device and haptic rendered objects could afford all participants access to interact with objects on-screen, using augmented touch, audio and sight, instead of purely sight. Tactile interaction of any form is highly intrinsic to designers' knowledge and understanding of the model's form and overall development.

After resolving pilot test issues, the main user test went on to establish if machine haptic technology was capable of offering design students more access to the prototype process set within the early stages of the design process. After analyzing user feedback and the metrics used to measure the affordances of the haptic interface, the results were presented and analyzed to conclude that machine haptics can be used by users with varying sight impairments to construct a virtual prototype in the third dimension, and this was achieved to a set industry standard time (5 minutes). It was also shown that users agreed positively with the post-trial questions that haptics can offer assistance to assemble prototypes, and enables non-sighted individuals to bypass the issues of visually centric graphical user interfaces, which are currently used within most of the systems at The Open University, and indeed most of the mainstream market computer-design software.

The next chapter presents the final chapter of this thesis, 'Conclusions Chapter 7'. Within this chapter, all of the significance of the findings from this research programme will be presented against the research questions and supporting hypotheses for this thesis overall.

7 Thesis conclusions

This final chapter will summarise the work described in the thesis. It discusses the limitations of the work and how they have been, in some part, overcome. Finally, future studies of inclusively led design tools are described.

The summary of the research carried out in this research programme is described in terms of three research questions and accompanying hypotheses.

7.1 Research questions

This section represents the research questions 1-3, and the relevant hypotheses for the thesis overall. Following is the discussion on how this study responded to the research questions and hypothesis (Hypo1,2,3) and highlights if the hypo1,2,3, is proven or not proven.

- **Research question 1,** Can a novel haptic design application, be used to assist non-sighted 'art-makers' to interact with virtual reality environments when aided by multimodal assistance?
    - Hypo 1 -The inclusion of a culmination of: a) an embedded rig and b) multimodal virtual haptic force (with additional virtual assistive audio elements) will enable non-sighted users to achieve the standard *(18.5seconds)* Wade's peg-in-hole time of healthy participants. *(Proven)*

- **Research question 2,** Can a multimodal interface allow better touch access for applied teaching and learning for non-sighted, visually impaired and fully sighted design novices?
    - Hypo 2 -Haptics is able to enable a set assembly task within an acceptable time and with limited difficulty to the users. *(Proven)*

- **Research question 3**, Is a haptic-based system usable and perceived to be so, by the two main user groups: non-sighted, visually impaired and fully sighted design novices?
  - Hypo 3 -Hatic technology, used as part of a multimodal interface, can aid a creative 'sensory-led' process and contribute to more inclusive learning, for non-sighted (NS) Art-Makers (AMs) and novice Designers/ students registered on a distance learning program. (Proven)

7.2 Feasibility and haptic utility for non-sighted art-makers

In the first half of Chapter 4, a detailed investigation of an inclusive Deep Dive study was conducted. A thematic analysis of art-makers feedback from the study offered that users felt the activities were 'fun, interesting, and new', and allowed the participants to reflect in new ways about their own creative touch interactions. Following the Deep Dive study, an adapted haptic version of the peg-in-hole test (fine motor test) was undertaken to further understand whether haptics could afford art-makers to utilize their fine motor skills in manual and machine haptic conditions.

A between-group, analysis of the peg-in-hole test showed there was a moderate difference between the two groups for duration and collision metrics. Further examinations of data revealed that art-makers results for time and collision were comparatively statistically lower than the sighted control group for Rig 1and2. This showed that through using haptics participants were enabled to complete the peg test in lower time with fewer collisions than the sighted group. There was negligible difference for duration and collisions, between-groups for Rig 3, where force feedback and sounds were decreased.

The Peg-in-hole test was conducted at the beginning of the month and the end of the month, to understand whether there was any learning taking place. The results showed that there was little difference in the results taken at the beginning and end of the month, meaning that no noticeable learning had taken place amongst the participants for this test. This could have possibly been due to the length of the period between testing was being too long, especially when it is understood that 90% of AMs held some form of learning need.

Overall in response to research question 1, the haptic interface used did afford non-sighted users better results than sighted peers which means it is possible to agree with the hypotheses, and reject the null hypothesis proposed for this test.

7.2.1 Industry-linked use of haptics

Chapter 6 reports on the second phase and final haptic empirical testing study, carried out in collaboration with The Open University (OU). The OU is one of the largest distance learning institutes in the UK and utilizes an Open access policy. Design students from the Engineering and Design School were specifically selected as distance learning design students were often shown to be limited by the challenge of facilitating an equivalent online version of a studio hands-on process. The Shape Assembly Test aimed to increase access to touch within the virtual realm and to mimic standard industry prototype assembly protocols for a range of individuals with differing sight acuities. The machine haptic support was designed to augment touch design activities, which are prominent in applied teaching disciplines. The peg-in-hole trials, shown in Chapter 4 phases, indicated that a multimodal haptic interface worked well for non-sighted user groups. Therefore, touch and audio feedback were intrinsically designed into the Prototype Test interface.

Through the use of a qualitative thematic analysis several themes surrounding the users' feedback were constructed. These were - *Understanding*, *Usability*, and *Fit for Purpose*. It was encouraging that 90% of the NS group were highly vocal about how the use of haptics had afforded them a unique access to the virtual realm. NS, VI feedback suggested that machine haptics had afforded them a better understanding of the depth perception and helped with the identification of 3D solid structures.

The quantitative results showed little difference for duration and collision data in the between-groups analysis as shown through Mann-Whitney U tests. Therefore, the use of haptics to assemble a prototype, supported all design student participants the tooling to achieve the design industry standard time of > 5 mins to assemble a prototype.

In response to RQ2, did a multimodal interface level the access for NS, VI students to help them engage more fully with virtual prototype assembly, the answer is yes. Without haptics, NS,VI Design students **would not** previously have been able to embark upon this type of hands-on access at the Open University.

From both haptic testing phases, the majority of non-sighted, visually impaired and fully sighted users offered encouraging and positive evaluations. The users offered that the haptics rigs were, 'easy to use', and easy to understand, and some stated the experience was 'fun'.

From the testing conducted with The Open University students, it was clear that OU students were more educated in design practice, and more experienced in designing from the germinal stages using manual and computer-aided design processes. The Open University students were also eager to use interactive 'Future Technologies' which would increase their own skills base. The NS students from the OU were more knowledgeable about what was expected of them within a formal testing environment and they understood how to use a Think-Aloud technique. To that extent, it was encouraging that although the students had all the relevant background knowledge of design, and design testing they still evaluated the haptic interface as 'interesting' and stated that the process was 'engaging'. The majority of OU NS, VI students stated that they were encouraged that there was accessible and inclusive testing for TEL in place, with the aim of increasing NS tactile interactions with digital design process. They acknowledged that without such testing they would be unable to share the same digital facilities as sighted design peers.

7.2.2 Limitations

The approach taken in working with users to integrate user-needs into two haptic interfaces overall has been shown to be effective. But it is important to note the limitations of the empirical studies in this thesis. The following highlight the limitations, and these are connected to the three research questions which are shown below.

RQ 1.Can a novel haptic design application, be used to assist non-sighted 'art-makers' to interact with virtual reality environments when aided by multimodal assistance?

Machine haptics were investigated for use with sound to assist non-sighted art-makers to complete a known peg-in-hole-motor skills task. To the researcher's knowledge, this test has never been previously trialed with non-sighted participants using a haptic device. However, the user's interactions held some limitations that need to be considered for future work. It has been previously discussed that the non-sighted community are not a heterogeneous group, and therefore the haptic force feedback, screen scale, color, contrast was not changed, in this instance, to suit the single participant's needs. This could have limited the guidance and assistance for each individual and methods should be considered where the force can be tuned to the user's needs and changed at will. Secondly, this study was tested over a month, to analyze whether any learning or understanding had taken place, the results showed a small amount of understanding through qualitative feedback but statistically there was little difference. The time between tests could be shortened to understand if any learning had taken place over shorter increments of time and what type of learning had taken place.

RQ 2 Can a multimodal interface allow better touch access for applied teaching and learning for non-sighted, visually impaired and fully sighted design novices?

The Shape Assembly test in Chapter 6 investigated where to use haptics to enhance learning specifically within the early phase of design. Scali et al., (Scali.S., 2013) showed that it was feasible to use haptics in the early phase of the design process, as typically this is where designers need to be more hands-on with materials and process. This thesis chose to work with a simple block prototype design, to allow all participants to simply place the blocks together within the accepted 5 minute assembly period. However, this testing phase only offered one form of multimodal condition, e.g. moderate force guidance and a small selection of sounds. In the previous peg-in-hole test, art-makers were able to access a range of multimodal conditions, therefore it was easier to select the condition which was more effective in assisting non-sighted participants to complete the test with better times and collision rate than the fully sighted control group. The Shape Assembly test limited participant's choice of a range of haptic and sound conditions, which could have offered more effective qualitative and quantitative results.

Secondly, the single point haptic device used in all empirical testing in this study limited users' interaction and contact with the prototype model to one single point. Human haptics offers five points of contact and the palm, in order to feedback cutaneous and kinesthetic feedback, to allow more understanding of the object via a wider tactile feedback.

RQ 3, is haptic-based system usable and perceived to be so, by the two main user groups: non-sighted, visually impaired and fully sighted design novices?

All empirical testing within this thesis programme was conducted using a single point haptic device, which can only make contact with a virtual object via one point of contact. The human hand can make contact with objects through five digits and a palm, using cutaneous and kinesthetic modes of interaction to understand the object in greater detail. The advantages of the particular single point device selected for this study are understood across the haptic community: to offer precise locations in space, six degrees of freedom of force guidance, controlled tracing and contouring of a solid virtual shape etc... However, to go back to MacLean's(MacLean.K.E, 2008) notion of passing the haptic Turing test—attaining the ideal state at which the user is unable to distinguish the feel of real versus rendered objects - the Geomagic Touch™ device cannot yet pass the Turing test. However, it was deemed that this particular device could offer the most benefits to non-sighted and visually impaired participants due to the levels of degrees of freedom, simplicity of use and force guidance. In future work it would be interesting to examine a mix of haptic devices for use by non-sighted individuals, or to use two Geomagic Touch™ devices, one stylus in each hand. It is pertinent to note, that within the Think-Aloud feedback, for both empirical tests, several non-sighted participants commented that they would have liked to use both hands to interact more fully with the virtual objects.

It is possible due to the small numbers of participants in each of the main case studies that the achievements or limitations of the case study could be down to the individual's achievements or limitations. However, as the researcher works as an inclusive designer, whose primary focus is on increasing individual's quality of interactions and parity of access, and as the tests above reveal this was achieved, then the issue of smaller numbers could be conceded. However, the issue of working with larger group numbers, for further testing should be a main consideration, for future work with the Open University, who would wish to work with larger numbers to fully assess quality and the limitations of haptics prior to embedding this form of TEL into any of their modules of learning.

7.3 Future work

In this study, haptic research was done to afford greater access and understanding of NS, VI PC users. Test designs were structured around user need whilst using MH to increase their fine motor skills and to augment touch in a prototype assembly haptic rendered space. The haptic device selected for the testing phases was the desktop kinesthetic Geomagic Touch™. Although this was shown to afford assistive force feedback, it did appear to cause restrictions to users as the device was desk-bound, and sat within a computer lab on campus.

The current planning for future haptic research will explore how a mobile haptic application could afford Design distance students access to haptic interactions on a daily basis. The specific area of design practice being considered to translate to haptics is drafting and drawing. Due to the peripatetic nature of many the OU students, much of the virtual learning activity is interacted with whilst the student is commuting to work, or even traveling the globe. Design modules, due to their complex visual and interactive nature, are difficult to be entirely viewed, from mobile displays rather than desktop displays. Added to this, often being mobile can present issues with concentration and add more pressure to focus visually. Future research aims to examine how to combat the 'inattentionals[22]' created from being mobile. The future work will also explore how gesture-based haptics could aid the immediacy of creative expression through drawing and drafting on the move. To do this the study will first try to understand which form of gesture haptics (cutaneous or kines-thetic) would be most useful and natural to students to aid sketching and drawing whilst mobile. Along with a collaborative group of OU academics and learning technologists, future work will draw out the potential benefits of 'gesture-based' haptics for drawing and drafting, as well as understanding how the addition of multimodal haptic widgets /buttons could also enhance user interaction experience with applied learning tasks.

[22] Published by MIT in 1998, a psychological lack of attention that is not associated with any vision defects or deficits. Wikipedia 2017.

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Appendices Content listing

APPENDIX A - RAW DATA (QUALITATIVE AND QUANTITATIVE) FROM DD and ‘NHPT’

A1 – Raw data from DD Talking stick themes (Activity- questions, Think-Aloud)

A2 – Raw data from PICTIVES test (Activity and Think-Aloud)

A3 – Raw data Assisting Tactile Tool Use (Questions and Observation)

A4 – Raw data Art Making Process (Questions and Observation)

A5 – Raw data Learning Effective Touch (Feedback from AMs Think-Aloud)

A6 – Raw data Peg-in-Hole Test (Think-Aloud)

A7 - Raw data scores for agreement to questionnaire about haptic technology use

A8 – Touch coding system

A9 – Consent letter DD and Peg-in-hole test

A10- DD instructions and ruling

A11 – Raw Data Peg-in-Hole quantitative

APPENDIX B – RAW DATA (QUALITATIVE AND QUANTITATIVE THE SHAPE ASSEMBLY TEST)

B1– Consent form for shape assembly

B2 – Ethics confirmation for pilot and main study

B2 – Project research planning

B3 – Raw data spss

B4 – Nivo raw data

B5 – Pilot test, raw data

B6- Cohens Kappa interater agreement

B7 – Nvivo raw data shape assembly

A1-A11 Collections of raw data,

A1,Results from DD Talking stick themes	A2, Results from PICTIVES test
Responses from '**Objects and Touch'** interview within studio. Questions: • How do you use touch in the studio? • How do you interact with objects? • What do you like and dislike about using touch to interact with artwork? • Do you have your own objects and tools? • I don't like the others' here to tell me what some'mat' [sic] feels like. I like to do it fo' m'self [sic]. • …yeah, mi too [sic], I'm like that. Mi'[sic] mum picks things up and passes [sic] them to me, an it drives mi' mad. I really don't it! I like to search in my own time for my own things for m'self [sic] then I get to search more…and I like doing that. • If, erm, if you want my view….erm I think, I could tell ya[sic] what all the objects in this room are in speedy time. • I want to say, right,… I want to say right, that I like just keeping my own personal objects and tools over here in my toolbox. I can then just help mi'self and I can lock it too. • I am less likely to trial touch in the studio, as there are sharp things, dangerous, ya see. I know at home where they all are at 'ome[sic], my mum stops me from touching them on my own. **A tangent discussion on Assistive Technology(AT) and adaptions** Participants discussing the best and worst AT available to them and things they often use.	Response from ***Pictives Think-Aloud*** technique. Narrative offered to AMs prior to the PICTIVE activity This activity is designed to help you all decide how we should layout the digital touch task, to assist you using the touch technology. What we would like you all to do is layout the test with the objects we have gathered. I would also very much like you all to talk about what you are doing as you do it so we can record the discussion. *Text gathered through think-aloud technique during activity • I am going to put this box here, right in front of me, so I can touch it again quickly if I need to… • So … erm right…I am going to move my hand to get a wooden shape now… • Erm, ha ok…I don't know what I should say … so I am going to move this here, as I am left-handed. Could you make the haptics for me as a left-handed person? I never get anything that feels good to hold for me[sic]. • I am moving my right hand to the box to test the distance to the box….I can feel the inside of the box and I can feel the blocks near the box. • I can feel that (x) has placed that block there but I want to move it up a bit, can I do that? • Can I ask (named individual) where to put things? …oh… ok well I am happy to put things in the places where everyone else likes em to be.

- I like my wardrobe gadget, I can pass it through my wardrobe and it selects acti – tags, its great. And I don't have to ask my to help me dress [sic]

- I think the magnifying kit makes me look old (laughing)"

- Yeah, it's what [sic] grannies use (sighing and laughing)

A3: Assisting Tactile Tool Use

(SEMI-STRUCTURED INTERVIEW)

QUESTIONS

THE FOLLOWING QUESTIONS WERE USED TO GAIN THE RESPONSES WHICH WOULD HELP TO GUIDE USER TACTILE REFERENCES FOR THE HAPTIC INTERFACE.

- HOW DO YOU USE THE TOOLS IN THE STUDIO WITH YOUR OWN ASSISTIVE TECHNOLOGY?
- WOULD YOU ALSO OFFER HOW YOU WORK WITH TOUCH ADAPTED TECHNIQUES.

- ANSWERS:
  - The staff here are really good at helping us all [sic] use tools in the workshop. I like using the special bottles with shapes on for paint.
  - I use a special stone…ok well erm… it shows me [sic] where the bottom corner is, but (x names another person) uses a plastic corner protector, but they don't have any more of those in stock ere,. [sic].
  - *I don't have a system, I just feel the edges of the table and then push my hand forward in a line like this… until I reach my tool (shows researcher pushing hand along the table)*

A4: Art making processes

QUESTIONS

THE FOLLOWING QUESTION WAS USED TO GAIN RESPONSE WHICH WOULD HELP TO GUIDE THE TYPES OF ADAPTIONS USED

- HOW DO YOU USE TOUCH AND ART-MAKING PROCESSES,
- WHO HELPS YOU?
- DO YOU NEED ANY HELP?
- HOW DO YOU USE TOOLS FOR YOUR OWN SPECIAL ARTWORK?

- ANSWERS
  - For me, I get help from my Assistant. Mandy helps me get to my seat, and gives me my things. I have my own box of felt and collection of colors that I always like to use.
  - Well, I get the beads on of the bag, like this…(picks up and shows off the bead)…then I feel the edges or feel the way it feels between my fingers and if I like the bead I use it. Simple really….
  - I will only use this (shows a paint palette scrapper, its chunky and I like it in this hand (shows the tool in the hand, gripping the tool handle by the neck of the tool).
  - I sit over here to make paper models, and I always use a round tin box. I like round shapes really.

A5, Learning effective touch

OBSERVATIONS AND QUESTIONS –

HOW HAVE YOU LEARNED HOW TO TOUCH?
DO YOU TOUCH AT HOME IN THE SAME WAY AS YOU USE TOUCH IN THE STUDIO?

- I learned how to touch… like this from birth I suppose…so, I have never really known anything else. It's hard to explain how I touch, as I am always touching stuff maybe sometimes stuff I shouldn't touch…(laughs)
- I touch at home differently to how I touch here (pointing around him in the studio). Does that help?...I use sticky Braille tape at home and I leave things so I know I can pick it back up… or oh yeah I use a braille tape for my clothes too so I don't look stupid when I get dressed, with all the different colors and that.
- I like feeling coloured paint – Do you like the feel of my purple? (sic)

A6, NHPT feedback

- ...the last one really frustrated me…..

I found I was waiting for guidance, but it never came.

- I liked this second test the best [sic]..
- …why can't I just work with number 2?
- I missed the force from rig 2.. as in rig 3 I just didn't feel it… it was just like a car which wouldn't start… is that correct?
- I liked the pushing force, I felt it like wham…[sic] all of a sudden I got pushed to the block…straight away…[sic].
- I felt that the number 2 rig, was much better than my last test set [sic].
- Was I fast? I felt like it was a fast result that

A7, Raw data scores for agreement to pre NHPT questionnaires

	1	2	3	4	5	6	TOTAL SCORE
Q1	5	7	8	8	9	7	44/60 M=7.[illegible]
Q2	7	7	8	7	7	8	44/60 M=7
Q3	8	8	7	8	8	8	47/60 M=8
Q4	7	8	8	7	8	7	45/60 M=7.5
Q5	8	7	8	8	8	8	47/60 M=8
Q6	4	5	5	5	4	3	26/60 M=4.5
Q7	7	8	8	9	8	7	47/60 M=8

PARTICIPANTS 1-3 = NS PARTICIPANTS 4-6 = FS

The participants were given a series of seven questions post-test to agree or disagree on a scale of 1-10. (10 being definitely agree and 1 being poor agreement)

The questions were:

1. Would you agree the haptic test assisted you?
2. Did you enjoy the experience?
3. Would you use the device again?
4. Would you recommend others to use the device?
5. How well did rig 1 and 2 assist you?
6. How well did rig 3 assist you?
7. Would you like to use the device in the future

A8: Touch coding observed touch within each task	**TOUCH CODING SYSTEM**
Touch Context INSTANCES OF DIFFERENT TOUCH COLOUR CODE – (RED, GREEN, BLUE)	
• 5 X AMS -EACH TOUCH ACTIVITY WAS RECORDED AND EXAMINED WITH BY TWO INTER-RATERS ACROSS 35MINS PERIOD. RED ACTIVE = EXPLORING OBJECTS, GREEN PASSIVE= KNOCKING INTO AN OBJECT, BLUE REPEATED = TOUCH USED TO DOUBLE CHECK TACTILE DETAILS.	
Art Making process	PICKING UP AND MOVING TOOLS - ACTIVE ACCIDENTAL TAPPING- PASSIVE CONTOURING - REPEATED
PICTIVE Process	PICKING UP AND MOVING OBJECTS - ACTIVE, TRAILING DIGITS ACROSS TABLE - PASSIVE, TRACING OBJECTS-REPEATED
Tool Use	ENCIRCLING TOOL - ACTIVE, TAPPING HANDLE ON TOOL- PASSIVE, CHECKING TOOL - REPEATED

A9 Consent form (Sample)

R09/LJB/LJB746

Dear Colleague,

<u>Consent form</u>

Project Title: Deep Dive NHPT Test

Researcher: Lisa Bowers

Supervisor: Dr. Farshid Amirabdohallian (University Hertfordshire)

The following is a consent form which consents to a controlled intervention with haptic testing equipment to complete a simple peg test. The consent will cover the following points:

I have received information about this research project.

I understand the purpose of the research project and my involvement in it.

I understand that I may withdraw from the research project at any stage.

I understand that my personal result will remain confidential and I wouldn't be indented if the information may be published.

I have been informed that might be taken pictures and videos during the study, which may be published.

I agree with the term above and indicate my agreement by signing here:

Name of participant:____

Date:_______________

Signature: ________________________________

Yours sincerely

Lisa Bowers (Lead research)

A10, Deep Dive aims and instructions

- Talking Stick:

Instructions for the talking stick process – The talking stick is a communication device to allow all members of the user group to speak out about their thoughts and reactions on the questions and topics offered by the researcher. In order to speak the group member must first hold the stick in a chosen hand, then speak to the group. Each group member holding the stick should not speak for longer than 10 mins, if the rest of the group wish to respond to any of the content from the stick holder they should raise their hand. The stick will then pass to them, when all queries or additional information has been added then the stick will immediately pass to the next member. (IDEO adapted ruling – everyone should have a voice)

Assisting tactile tool use:

Aims

- To gather evidence of the NS AM practice tool use within the adapted studio.
- To further understand any anomalies of tool use compared to non-disabled studio
- To gain further insight to AMs understanding of hand tools as a complex learning needs.
- To further understand the AM individual as a person adapting their tool use to aid their work as a NS person.

Instructions:

Researcher to sit next to the participant for three sittings of 15mins across the 4 hr session. The initial 15 min session the researcher should observe tool use without prompts. The next two 15 mins sessions researcher should use the questions as prompts. The usual ethical procedures apply, the participant can leave the session at any time. The participant's assistant and trainer will be present, along with other studio users.

Art making process (shared aims with assistive tactile tool use)

Researcher to sit next to the participant for three sessions of 15 mins across the 4 hr session. The initial 15 min session the researcher should observe any unusual methods to work with artmaking process e.g. specific adaptions to print-making process. In the next 15 mins slot the questions should guide the researcher and prompt the participants to inform on their processes.

Learning Effective touch orientation

Initial conversations use questions and then consistently take field notes on the AMs touch and touch perceptions. Cross-reference and confirm field notes with experts (assistants and Henshaws staff)

PICTIVES (working towards NHPT)

As part of the preparation for peg-in-hole test AMs handling and user-led layout of peg-in-hole test setup needs user input to guide the best layout to suit orientation and needs of user. Offer PICTIVE equipment to participants (no=5). The AMs and staff should be guided in how to structure the layout of the haptic interface and the original set-up of Wades peg-in-hole test, but other than this the placing of home cues and peg lay-out should be left to users. The positioning of the layout should be noted and not interrupted for each AM and a consensus of positioning will be noted and used. (*scoping for manual handling should be noted and confirmed from recording)

A12 Raw data for wade's test (nhpt)

NS =1-3, FS=4-6

1. DURATION

Participant	Rig1-3	BM-EM	Testiter 1	Testiter 2	Testiter3	Testiter4	Total
1	1	2	13	40	17	13	21
1	2	1	5.4	11	11	11	10
1	2	2	8.8	8.8	9.8	7.3	9
1	3	1	20	41	17	50	32
1	3	2	27	8.8	23	23	20
1	1	1	15	18	15	15	16
2	1	1	9.6	7.5	6.1	40	16
2	1	2	9.6	6.4	5.3	7.5	7
2	2	1	6	8.7	8.2	8.7	8
2	2	2	5.2	6.4	8.2	7	7
2	3	1	24	24	25	15	22
2	3	2	15	11	10	9.5	11
3	1	1	7.5	15	7.6	16	12
3	1	2	16	0	20	14	13
3	2	1	9.4	7.2	9.2	5.9	8
3	2	2	19	12	9.7	12	13
3	3	1	25	21	18	12	19
3	3	2	26	37	21	23	27
4	1	1	28	14	22	18	21
4	1	2	13	19	29	16	19
4	2	1	17	20	12	15	16
4	2	2	13	15	29	29	22
4	3	1	29	17	27	15	22
4	3	2	39	56	27	58	45
5	1	1	29	12	19	16	19
5	1	2	18	29	27	41	29
5	2	1	16	14	8.2	8.2	12
5	2	2	17	20	12	15	16
5	3	1		20	16	14	17
5	3	2	39	27	58	56	45

6	1	1	9	6.4	12	10	9
							Cont..
Partiticipant	**Rig1-3**	**BM-EM**	**Testiter 1**	**Testiter 2**	**Testiter3**	**Testiter4**	**Total**
6	1	2	9.6	12	9.6	7.5	10
6	2	1	8	14	9.7	8.8	10
6	2	2	5.2	5.2	9.7	7	7
6	3	1	24	14	14	18	18
6	3	2	15	14	14	18	15

2. COLLISION (NHPT)

Partpant2	Rig1-32	BM-EM2	event string	Iter1	Iter 2	Iter 3	Iter 4	total iteration 1-4
1	3	1	CH1	1	2	3	5	11
2	1	1	CH1	2	2	2	1	7
2	2	1	CH1	1	1	1	1	4
2	3	1	CH1	2	2	1	1	6
3	1	1	CH1	2	1	1	1	5
3	2	1	CH1	2	1	2	1	6
3	3	1	CH1	2	1	1	1	5
4	1	1	CH1	4	2	1	2	9
1	2	1	CH1	2	2	1	1	6
4	2	1	CH1	1	3	2	1	7
4	3	1	CH1	2	1	1	1	5
5	1	1	CH1	3	1	1	1	6
5	2	1	CH1	3	2	1	1	7
5	3	1	CH1	0	2	1	2	5
6	1	1	CH1	1	1	2	1	5
6	2	1	CH1	1	2	2	2	7
6	3	1	CH1	1	1	1	1	4
1	1	1	CH2	2	1	2	2	7
1	2	2	CH2	3	1	3	3	10
1	1	1	CH2	1	1	1	2	5
1	2	2	CH2	2	2	2	2	8
1	1	1	CH2	2	2	4	3	11
1	2	2	CH2	2	2	3	2	9
2	1	1	CH2	2	2	2	1	7
2	2	2	CH2	2	1	1	2	6
2	1	1	CH2	2	2	1	2	7
2	2	2	CH2	1	1	1	1	4
2	1	1	CH2	3	3	0	1	7
2	2	2	CH2	1	2	2	2	7

3	1	1	CH2	2	0	1	2	5
3	2	2	CH2	2	1	2	1	6
Partpant2	**Rig1-32**	**BM-EM2**	**event string**	**Iter1**	**Iter 2**	**Iter 3**	**Iter 4**	**total iteration 1-4**
3	1	1	CH2	3	0	0	0	
3	2	2	CH2	2	1	1	1	6
3	1	1	CH2	3	2	1	1	6
3	2	2	CH2	1	1	1	2	7
4	1	1	CH2	2	4	1	2	8
4	2	2	CH2	1	2	4	1	9
4	1	1	CH2	1	1	1	2	4
4	2	2	CH2	1	1	3	1	4
4	1	1	CH2	2	1	4	3	8
4	2	2	CH2	6	2	5	2	10
5	1	1	CH2	1	6	1	2	19
5	2	2	CH2	5	2	2	2	5
5	1	1	CH2	1	2	1	2	7
5	2	2	CH2	6	2	1	2	10
5	1	1	CH2	1	1	2	1	4
5	2	2	CH2	2	2	4	1	5
6	1	1	CH2	1	5	1	6	21
6	2	2	CH2	1	1	2	1	4
6	1	1	CH2	1	1	1	2	7
6	2	2	CH2	1	2	1	1	5
6	1	1	CH2	2	1	1	1	4
6	2	2	CH2	2	2	1	2	6
1	1	1	CH3	2	2	2	2	6
1	2	2	CH3	2	3	1	2	9
1	1	1	CH3	2	2	3	2	7
1	2	2	CH3	3	1	1	1	7
1	1	1	CH3	1	2	2	1	6
1	2	2	CH3	1	3	2	1	8
2	1	1	CH3	1	2	1	2	9
2	2	2	CH3	1	1	1	2	5
2	1	1	CH3	3	1	2	1	4
2	2	2	CH3	2	2	2	2	7
2	1	1	CH3	1	1	2	2	6
2	2	2	CH3	1	3	1	1	9
3	1	1	CH3	2	1	1	1	5
3	2	2	CH3	1	2	2	1	5
3	1	1	CH3	3	1	1	1	5
3	2	2	CH3	1	1	1	2	6
3	1	1	CH3	2	2	3	1	5

3	2	2	CH3	3	1	1	2	9
4	1	1	CH3	2	1	2	1	4
4	2	2	CH3	3	1	1	1	6
Partpant2	**Rig1-32**	**BM-EM2**	**event string**	**Iter1**	**Iter 2**	**Iter 3**	**Iter 4**	**total iteration 1-4**
4	1	1	CH3	4	1	1	1	6
4	2	2	CH3	5	2	5	2	7
4	1	1	CH3	1	2	3	5	15
4	2	2	CH3	1	1	7	2	10
5	1	1	CH3	4	3	1	4	19
5	2	2	CH3	2	1	1	1	4
5	1	1	CH3		1	1	2	5
5	2	2	CH3	5	1	1	2	8
5	1	1	CH3	1	2	3	2	7
5	2	2	CH3	1	3	6	2	8
6	1	1	CH3	1	7	1	3	21
6	2	2	CH3	1	1	1	2	5
6	1	1	CH3	2	1	2	1	4
6	2	2	CH3	2	1	2	1	5
6	1	1	CH3	2	1	2	2	6
6	2	2	CH3	1	1	2	1	6
1	1	1	CH4	2	1	2	1	6
1	2	2	CH4	1	1	1	2	7
1	1	1	CH4	2	1	1	1	4
1	2	2	CH4	2	2	1	1	6
1	1	1	CH4	2	1	2	1	4
1	2	2	CH4	2	1	4	4	9
2	1	1	CH4	1	1	2	4	11
2	2	2	CH4	2	1	1	1	6
2	1	1	CH4	1	1	2	2	6
2	2	2	CH4	2	1	2	1	5
2	1	1	CH4	1	1	1	1	6
2	2	2	CH4	2	1	1	1	4
3	1	1	CH4	1	1	2	1	5
3	2	2	CH4	1	2	2	2	7
3	1	1	CH4	1	1	2	1	6
3	2	2	CH4	1	1	2	1	5
3	1	1	CH4	1	1	2	2	6
3	2	2	CH4	2	1	2	3	7
4	1	1	CH4	1	1	1	1	5
4	2	2	CH4	2	1	1	1	4
4	1	1	CH4	1	1	1	1	5
4	2	2	CH4	1	1	1	1	4

4	1	1	CH4	1	1	2	1	5
4	2	2	CH4	1	2	1	2	7
5	1	1	CH4	2	1	1	5	8
5	2	2	CH4	1	1	1	1	4
Partpant2	**Rig1-32**	**BM-EM2**	**event string**	**Iter1**	**Iter 2**	**Iter 3**	**Iter 4**	**total iteration 1-4**
5	1	1	CH4		4	1	2	8
5	2	2	CH4	1	1	1	1	5
5	1	1	CH4	2	1	1	1	4
5	2	2	CH4	2	1	1	1	3
6	1	1	CH4	1	1	1	1	4
6	2	2	CH4	2	1	2	1	5
6	1	1	CH4	4	1	1	2	7
6	2	2	CH4	2	1	1	1	4
6	1	1	CH4	2	2	1	1	6
6	2	2	CH4	1	1	1	1	7
1	1	1	CH5	2	1	2	1	5
1	2	2	CH5	4	1	2	2	7
1	1	1	CH5	3	1	1	1	5
1	2	2	CH5	2	2	2	1	6
1	1	1	CH5	1	4	1	1	11
1	2	2	CH5	1	3	4	4	11
2	1	1	CH5	2	4	1	4	14
2	2	2	CH5	1	1	1	2	5
2	1	1	CH5	4	2	1	1	5
2	2	2	CH5	1	1	1	1	5
2	1	1	CH5	1	2	2	1	5
2	2	2	CH5	1	4	4	1	11
3	1	1	CH5	2	1	1	2	8
3	2	2	CH5	1	4	2	1	7
3	1	1	CH5	4	1	2	1	5
3	2	2	CH5	1	1	1	2	7
3	1	1	CH5	2	1	3	2	5
3	2	2	CH5	1	1	2	2	10
4	1	1	CH5	1	1	1	2	6
4	2	2	CH5	1	1	1	1	5
4	1	1	CH5	2	1	1	1	4
4	2	2	CH5	2	1	2	2	5
4	1	1	CH5	1	2	1	2	7
4	2	2	CH5	1	4	1	1	8
5	1	1	CH5	3	2	1	6	11
5	2	2	CH5	1	2	1	1	5
5	1	1	CH5		1	2	1	4

5	2	2	CH5	2	1	1	1	7
5	1	1	CH5	1	1	3	2	5
5	2	2	CH5	1	1	1	1	5
6	1	1	CH5	2	1	2	2	6
6	2	2	CH5	1	2	1	1	6
Partpant2	**Rig1-32**	**BM-EM2**	**event string**	**Iter1**	**Iter 2**	**Iter 3**	**Iter 4**	**total iteration 1-4**
6	1	1	CH5	4	2	2	1	5
6	2	2	CH5	1	1	2	2	7
6	1	1	CH5	2	1	2	1	5
6	2	2	CH5	1	1	2	3	10
1	1	1	CH6	1	1	2	3	7
1	2	2	CH6	2	1	1	2	7
1	1	1	CH6	4	1	1	1	4
1	2	2	CH6	2	1	1	1	4
1	1	1	CH6	2	2	1	1	6
1	2	2	CH6	2	6	2	3	14
2	1	1	CH6	2	2	1	2	8
2	2	2	CH6	2	1	1	1	5
2	1	1	CH6	3	1	5	2	6
2	2	2	CH6	2	1	5	1	9
2	1	1	CH6	1	1	3	2	10
2	2	2	CH6	1	3	5	3	12
3	1	1	CH6	1	2	2	3	12
3	2	2	CH6	2	1	2	1	5
3	1	1	CH6	3	1	2	1	5
3	2	2	CH6	1	1	1	1	5
3	1	1	CH6	2	1	3	1	5
3	2	2	CH6	2	2	1	2	10
4	1	1	CH6	1	1	1	1	4
4	2	2	CH6	2	1	1	2	6
4	1	1	CH6	1	1	1	1	5
4	2	2	CH6	2	2	1	2	6
4	1	1	CH6	1	2	2	1	6
4	2	2	CH6	2	4	2	3	10
5	1	1	CH6	3	2	1	6	12
5	2	2	CH6	1	1	1	1	4
5	1	1	CH6		3	1	1	7
5	2	2	CH6	2	2	1	1	7
5	1	1	CH6	1	2	2	2	6
5	2	2	CH6	2	1	3	2	5
6	1	1	CH6	1	2	2	2	9
6	2	2	CH6	2	1	2	2	6

6	1	1	CH6	5	2	2	2	8
6	2	2	CH6	2	2	2	1	6
6	1	1	CH6	1	1	1	2	7
6	2	2	CH6	1	1	1	1	8
1	1	1	CH7	2	1	1	1	5
1	2	2	CH7	1	1	1	1	4
Partpant2	**Rig1-32**	**BM-EM2**	**event string**	**Iter1**	**Iter 2**	**Iter 3**	**Iter 4**	**total iteration 1-4**
1	1	1	CH7	1	2	1	1	5
1	2	2	CH7	2	2	3	1	6
1	1	1	CH7	4	1	1	1	6
1	2	2	CH7	4	1	2	2	5
2	1	1	CH7	1	1	1	2	7
2	2	2	CH7	2	2	1	1	8
2	1	1	CH7	1	2	1	2	9
2	2	2	CH7	3	1	1	1	4
2	1	1	CH7	2	2	1	1	6
2	2	2	CH7	1	1	1	2	5
3	1	1	CH7	1	1	1	1	6
3	2	2	CH7	1	1	1	1	5
3	1	1	CH7	1	2	1	1	5
3	2	2	CH7	1	1	1	1	4
3	1	1	CH7	1	2	1	1	5
3	2	2	CH7	1	1	1	1	4
4	1	1	CH7	1	2	1	1	5
4	2	2	CH7	1	1	1	1	4
4	1	1	CH7	1	1	1	1	4
4	2	2	CH7	1	2	1	2	6
4	1	1	CH7	1	2	1	1	5
4	2	2	CH7	1	1	1	1	4
5	1	1	CH7	2	2	1	1	5
5	2	2	CH7	1	1	2	1	4
5	1	1	CH7	0	1	1	1	5
5	2	2	CH7	1	1	1	1	5
5	1	1	CH7	1	2	2	2	6
5	2	2	CH7	4	2	3	1	5
6	1	1	CH7	1	1	2	2	7
6	2	2	CH7	2	2	4	1	6
6	1	1	CH7	2	2	2	2	12
6	2	2	CH7	3	1	2	1	5
6	1	1	CH7	1	1	1	1	6
6	2	2	CH7	2	1	1	1	5
1	1	1	CH8	1	1	1	1	6

1	2	2	CH8	2	2	2	1	5
1	1	1	CH8	2	1	1	2	7
1	2	2	CH8	2	1	1	1	4
1	1	1	CH8	1	2	3	1	6
1	2	2	CH8	1	2	5	3	10
2	1	1	CH8	1	2	2	5	14
2	2	2	CH8	2	1	1	1	5
Partpant2	**Rig1-32**	**BM-EM2**	**event string**	**Iter1**	**Iter 2**	**Iter 3**	**Iter 4**	**total iteration 1-4**
2	1	1	CH8	1	1	2	1	4
2	2	2	CH8	5	1	2	1	5
2	1	1	CH8	1	1	1	1	6
2	2	2	CH8	1	1	2	2	5
3	1	1	CH8	1	1	1	1	9
3	2	2	CH8	2	1	1	1	4
3	1	1	CH8	1	1	2	1	4
3	2	2	CH8	2	2	2	1	6
3	1	1	CH8	1	1	1	1	6
3	2	2	CH8	1	3	1	2	7
4	1	1	CH8	1	4	1	1	8
4	2	2	CH8	1	1	2	1	4
4	1	1	CH8	3	2	2	2	7
4	2	2	CH8	3	1	3	1	5
4	1	1	CH8	2	1	1	3	8
4	2	2	CH8	1	2	2	3	9
5	1	1	CH8	2	4	2	3	12
5	2	2	CH8	1	1	1	2	7
5	1	1	CH8	0	1	1	1	4
5	2	2	CH8	3	2	2	1	6
5	1	1	CH8	1	1	2	1	5
5	2	2	CH8	1	1	5	2	5
6	1	1	CH8	1	2	1	4	14
6	2	2	CH8	2	1	1	1	4
6	1	1	CH8	4	1	2	1	4
6	2	2	CH8	5	2	2	2	7
6	1	1	CH8	1	1	2	1	6
6	2	2	CH8	1	1	2	3	10
1	1	1	CH9	1	1	1	3	11
1	2	2	CH9	1	1	1	1	4
1	1	1	CH9	2	1	1	1	4
1	2	2	CH9	1	2	1	1	5
1	1	1	CH9	1	1	1	1	4
1	2	2	CH9	1	2	3	2	7

2	1	1	CH9	1	1	0	3	8
2	2	2	CH9	1	1	1	0	2
2	1	1	CH9	3	1	2	1	4
2	2	2	CH9	1	2	2	2	7
2	1	1	CH9	1	1	4	1	5
2	2	2	CH9	1	3	4	2	12
3	1	1	CH9	1	1	2	1	7
3	2	2	CH9	2	1	1	1	5
Partpant2	**Rig1-32**	**BM-EM2**	**event string**	**Iter1**	**Iter 2**	**Iter 3**	**Iter 4**	**total iteration 1-4**
3	1	1	CH9	3	1	1	1	4
3	2	2	CH9	3	1	1	1	4
3	1	1	CH9	1	1	1	2	6
3	2	2	CH9	1	3	2	2	9
4	1	1	CH9	1	4	2	1	10
4	2	2	CH9	1	1	1	2	6
4	1	1	CH9	1	3	2	2	7
4	2	2	CH9	2	1	1	2	6
4	1	1	CH9	1	2	2	1	5
4	2	2	CH9	2	3	5	4	10
5	1	1	CH9	4	2	3	2	11
5	2	2	CH9	1	2	2	2	8
5	1	1	CH9	0	2	1	1	7
5	2	2	CH9	2	1	2	2	8
5	1	1	CH9	1	1	1	2	6
5	2	2	CH9	1	2	3	1	4
6	1	1	CH9	2	5	1	2	12
6	2	2	CH9	1	1	1	1	4
6	1	1	CH9	3	1	2	1	4
6	2	2	CH9	1	1	1	2	7
6	1	1	CH9	1	1	2	1	4
6	2	2	CH9	1	1	2	3	9
1	1	1	IH1	1	1	1	3	7
1	2	2	IH1	2	1	1	1	4
1	1	1	IH1	1	1	1	1	4
1	2	2	IH1	1	1	1	1	4
1	1	1	IH1	1	1	1	1	5
1	2	2	IH1	1	1	1	1	4
2	1	1	IH1	1	2	1	1	5
2	2	2	IH1	1	1	1	2	5
2	1	1	IH1	1	1	2	1	4
2	2	2	IH1	1	1	2	1	5
2	1	1	IH1	1	1	0	1	5

2	2	2	IH1	1	1	1	1	3
3	1	1	IH1	1	1	1	1	4
3	2	2	IH1	1	1	2	1	4
3	1	1	IH1	1	1	1	2	6
3	2	2	IH1	1	1	1	1	4
3	1	1	IH1	2	1	1	1	4
3	2	2	IH1	1	1	1	1	4
4	1	1	IH1	2	1	1	1	4
4	2	2	IH1	1	1	1	1	5
Partpant2	**Rig1-32**	**BM-EM2**	**event string**	**Iter1**	**Iter 2**	**Iter 3**	**Iter 4**	**total iteration 1-4**
4	1	1	IH1	1	1	1	1	4
4	2	2	IH1	1	1	1	1	5
4	1	1	IH1	1	1	1	1	4
4	2	2	IH1	1	1	1	1	4
5	1	1	IH1	2	1	1	1	4
5	2	2	IH1	2	1	1	1	4
5	1	1	IH1	0	1	2	2	5
5	2	2	IH1	1	1	1	1	6
5	1	1	IH1	1	1	1	1	5
5	2	2	IH1	1	1	1	1	3
6	1	1	IH1	1	1	1	1	4
6	2	2	IH1	1	1	1	1	4
6	1	1	IH1	1	1	1	1	4
6	2	2	IH1	1	1	1	1	4
6	1	1	IH1	1	1	2	1	4
6	2	2	IH1	1	1	2	1	5
1	1	1	IH2	1	1	1	1	5
1	2	2	IH2	2	1	1	1	4
1	1	1	IH2		1	1	1	4
1	2	2	IH2	1	1	1	1	4
1	1	1	IH2	1	2	1	1	6
1	2	2	IH2	1	1	1	0	2
2	1	1	IH2	1	2	1	1	5
2	2	2	IH2	1	1	1	1	4
2	1	1	IH2	1	1	0	1	4
2	2	2	IH2	0	1	0	1	3
2	1	1	IH2	1	1	1	1	3
2	2	2	IH2	1	1	1	1	4
3	1	1	IH2	1	1	0	1	3
3	2	2	IH2	1	0	1	1	2
3	1	1	IH2	2	1	1	1	4
3	2	2	IH2	1	1	1	1	4

3	1	1	IH2	1	1	1	1	4
3	2	2	IH2	1	1	1	1	5
4	1	1	IH2	0	1	1	1	4
4	2	2	IH2	1	1	0	1	4
4	1	1	IH2	1	1	1	0	2
4	2	2	IH2	1	1	1	1	3
4	1	1	IH2	0	1	1	1	4
4	2	2	IH2	1	1	1	1	4
5	1	1	IH2	2	1	1	1	4
5	2	2	IH2	0	1	1	0	2
Partpant2	**Rig1-32**	**BM-EM2**	**event string**	**Iter1**	**Iter 2**	**Iter 3**	**Iter 4**	**total iteration 1-4**
5	1	1	IH2	0	1	1	1	4
5	2	2	IH2	1	1	1	1	5
5	1	1	IH2	1	1	1	1	3
5	2	2	IH2	1	1	1	1	3
6	1	1	IH2	1	1	1	1	4
6	2	2	IH2	1	1	1	1	4
6	1	1	IH2	1	1	1	1	4
6	2	2	IH2	0	1	1	1	4
6	1	1	IH2	1	1	1	1	4
6	2	2	IH2	1	1	1	1	4
1	1	1	IH3	0	1	1	1	3
1	2	2	IH3	1	1	2	1	4
1	1	1	IH3	1	1	1	1	5
1	2	2	IH3	1	1	1	1	3
1	1	1	IH3	1	1	1	1	4
1	2	2	IH3	1	1	1	1	4
2	1	1	IH3	1	1	1	1	4
2	2	2	IH3	1	1	1	1	4
2	1	1	IH3	1	1	1	1	4
2	2	2	IH3	1	1	1	1	4
2	1	1	IH3	1	1	1	1	4
2	2	2	IH3	1	1	1	0	3
3	1	1	IH3	1	1	1	1	4
3	2	2	IH3	1	1	1	1	4
3	1	1	IH3	1	1	1	1	4
3	2	2	IH3	1	1	1	1	4
3	1	1	IH3	5	1	1	0	3
3	2	2	IH3	1	1	1	1	4
4	1	1	IH3	1	1	1	0	3
4	2	2	IH3	1	1	4	1	8
4	1	1	IH3	4	1	1	1	7

4	2	2	IH3	1	1	4	1	4
4	1	1	IH3	4	1	1	4	10
4	2	2	IH3	1	1	1	0	6
5	1	1	IH3	2	1	1	1	4
5	2	2	IH3	1	1	1	1	7
5	1	1	IH3	0	0	1	1	3
5	2	2	IH3	1	1	1	1	5
5	1	1	IH3	1	1	1	1	4
5	2	2	IH3	1	1	1	1	3
6	1	1	IH3	1	1	1	1	4
6	2	2	IH3	1	1	1	1	4
Partpant2	**Rig1-32**	**BM-EM2**	**event string**	**Iter1**	**Iter 2**	**Iter 3**	**Iter 4**	**total iteration 1-4**
6	1	1	IH3	1	1	1	1	4
6	2	2	IH3	1	1	1	1	4
6	1	1	IH3	1	1	1	1	4
6	2	2	IH3	1	1	1	1	4
1	1	1	IH4	1	1	1	1	4
1	2	2	IH4	1	1	1	1	4
1	1	1	IH4	1	1	1	1	4
1	2	2	IH4	1	1	1	1	4
1	1	1	IH4	1	1	1	1	4
1	2	2	IH4	1	1	1	1	4
2	1	1	IH4	1	1	1	1	4
2	2	2	IH4	1	1	1	1	4
2	1	1	IH4	1	1	1	1	4
2	2	2	IH4	1	0	1	0	2
2	1	1	IH4	1	1	1	1	4
2	2	2	IH4	1	1	1	1	4
3	1	1	IH4	1	1	1	1	4
3	2	2	IH4	1	1	1	1	4
3	1	1	IH4	1	1	1	1	4
3	2	2	IH4	1	1	1	1	4
3	1	1	IH4	1	1	1	1	4
3	2	2	IH4	1	1	1	1	4
4	1	1	IH4	1	1	1	0	3
4	2	2	IH4	1	1	1	1	4
4	1	1	IH4	1	1	1	1	4
4	2	2	IH4	1	1	1	1	4
4	1	1	IH4	1	1	0	1	4
4	2	2	IH4	1	1	0	1	3
5	1	1	IH4	2	1	1	1	3
5	2	2	IH4	1	1	1	1	4

5	1	1	IH4	0	1	1	1	4
5	2	2	IH4	1	1	1	1	5
5	1	1	IH4	1	1	1	1	4
5	2	2	IH4	1	1	0	1	3
6	1	1	IH4	1	0	1	1	2
6	2	2	IH4	1	1	1	1	4
6	1	1	IH4	1	1	1	1	4
6	2	2	IH4	1	1	1	1	4
6	1	1	IH4	1	1	1	1	4
6	2	2	IH4	1	1	1	1	4
1	1	1	IH5	1	1	1	1	4
1	2	2	IH5	1	1	1	1	4
Partpant2	**Rig1-32**	**BM-EM2**	**event string**	**Iter1**	**Iter 2**	**Iter 3**	**Iter 4**	**total iteration 1-4**
1	1	1	IH5	1	1	1	1	4
1	2	2	IH5	0	1	1	1	4
1	1	1	IH5	1	1	1	1	4
1	2	2	IH5	1	0	1	1	3
2	1	1	IH5	1	1	1	1	3
2	2	2	IH5	1	1	1	1	4
2	1	1	IH5	1	1	1	1	4
2	2	2	IH5	0	1	1	1	4
2	1	1	IH5	1	1	1	1	4
2	2	2	IH5	1	1	1	1	4
3	1	1	IH5	1	0	1	0	1
3	2	2	IH5	1	1	1	1	4
3	1	1	IH5	1	1	1	1	4
3	2	2	IH5	1	1	1	1	4
3	1	1	IH5	2	1	1	1	4
3	2	2	IH5	1	0	1	1	3
4	1	1	IH5	1	1	1	1	4
4	2	2	IH5	1	1	1	1	5
4	1	1	IH5	1	1	1	1	4
4	2	2	IH5	0	1	1	1	4
4	1	1	IH5	1	1	0	1	4
4	2	2	IH5	1	0	1	1	2
5	1	1	IH5	2	0	1	1	2
5	2	2	IH5	1	1	0	1	4
5	1	1	IH5	0	1	1	1	3
5	2	2	IH5	0	1	1	1	5
5	1	1	IH5	1	1	1	1	4
5	2	2	IH5	1	1	1	1	3
6	1	1	IH5	1	1	1	0	2

6	2	2	IH5	1	1	1	1	4
6	1	1	IH5	1	1	1	1	4
6	2	2	IH5	0	1	1	1	4
6	1	1	IH5	1	1	1	1	4
6	2	2	IH5	1	0	1	1	3
1	1	1	IH6	1	0	1	1	2
1	2	2	IH6	1	1	0	1	4
1	1	1	IH6		1	1	1	3
1	2	2	IH6	1	1	1	1	4
1	1	1	IH6	1	1	0	1	4
1	2	2	IH6	1	1	1	1	2
2	1	1	IH6	1	1	1	1	4
2	2	2	IH6	1	1	1	1	4
Partpant2	**Rig1-32**	**BM-EM2**	**event string**	**Iter1**	**Iter 2**	**Iter 3**	**Iter 4**	**total iteration 1-4**
2	1	1	IH6	1	0	1	1	3
2	2	2	IH6	1	1	1	1	4
2	1	1	IH6	1	0	1	1	3
2	2	2	IH6	1	1	0	0	3
3	1	1	IH6	1	1	1	1	3
3	2	2	IH6	1	1	1	1	4
3	1	1	IH6	1	1	1	1	4
3	2	2	IH6	1	1	1	1	4
3	1	1	IH6	1	1	1	1	4
3	2	2	IH6	1	1	1	1	4
4	1	1	IH6	1	1	1	1	4
4	2	2	IH6	1	1	1	1	4
4	1	1	IH6	1	1	0	1	4
4	2	2	IH6	1	1	1	1	3
4	1	1	IH6	1	1	1	1	4
4	2	2	IH6	1	1	1	0	3
5	1	1	IH6	2	1	1	1	4
5	2	2	IH6	1	1	1	1	4
5	1	1	IH6	0	0	1	1	3
5	2	2	IH6	1	1	0	1	5
5	1	1	IH6	1	1	1	1	3
5	2	2	IH6	1	1	2	1	3
6	1	1	IH6	1	1	1	1	5
6	2	2	IH6	1		1	1	3
6	1	1	IH6	1	1	1	1	4
6	2	2	IH6	1	1	1	1	4
6	1	1	IH6		1	1	1	4
6	2	2	IH6	1	1	1	1	4

1	1	1	IH7	1	1		1	4
1	2	2	IH7	1	1	1		1
1	1	1	IH7	1	1	1	1	4
1	2	2	IH7	1	1	1	1	4
1	1	1	IH7	1	1	1	1	4
1	2	2	IH7	1	1	1	0	3
2	1	1	IH7	1	1	0	1	4
2	2	2	IH7	1	0	1	1	2
2	1	1	IH7	1	1	1	1	4
2	2	2	IH7	1	1	1	1	4
2	1	1	IH7	0	1	1	1	4
2	2	2	IH7	1	1	0	1	4
3	1	1	IH7	1	1	1	1	3
3	2	2	IH7	1	1	1	1	3
Partpant2	**Rig1-32**	**BM-EM2**	**event string**	**Iter1**	**Iter 2**	**Iter 3**	**Iter 4**	**total iteration 1-4**
3	2	2	IH7	1	1		0	3
3	1	1	IH7	1	1	1	0	2
3	2	2	IH7	1	1	1	1	4
4	1	1	IH7	1	1	0	1	4
4	2	2	IH7	1	1	1	0	2
4	1	1	IH7	1	1	1	1	4
4	2	2	IH7	0	1	1	1	4
4	1	1	IH7	1	1	1	1	4
4	2	2	IH7	0	0	1	1	3
5	1	1	IH7	2	1	1	1	3
5	2	2	IH7	1	1	1	1	4
5	1	1	IH7	0	1	1	1	3
5	2	2	IH7	0	1	1	1	5
5	1	1	IH7	1	1	1	1	4
5	2	2	IH7	1	1	2	1	3
6	1	1	IH7	1	1	1	1	4
6	2	2	IH7	1	1	1	1	4
6	1	1	IH7	1	1	1	1	4
6	2	2	IH7	1	1	1	1	4
6	1	1	IH7	1	1	1	1	4
6	2	2	IH7	1	1	1	0	3
1	1	1	IH8	1	1	1	0	3
1	2	2	IH8	1	1	1	1	4
1	1	1	IH8	0	1	1	1	4
1	2	2	IH8	1	1	1	1	4
1	1	1	IH8	0	1	1	1	4
1	2	2	IH8	0	1	1	1	3

2	1	1	IH8	1	1	1	1	4
2	2	2	IH8	1	1	1	1	3
2	1	1	IH8	1	1	1		2
2	2	2	IH8	1	1	1	1	4
2	1	1	IH8	1	1	1	1	4
2	2	2	IH8	1	1	1	1	4
3	1	1	IH8	0	1	0	1	4
3	2	2	IH8	2	1	1	1	3
3	1	1	IH8	1	1	0	1	4
3	2	2	IH8	1	1	1	1	2
3	1	1	IH8	1	1	1	1	5
3	2	2	IH8	1	1	1	0	3
4	1	1	IH8	1	1	1	1	4
4	2	2	IH8	1	1	1	1	4
4	1	1	IH8	1	1	1	1	4
Partpant2	**Rig1-32**	**BM-EM2**	**event string**	**Iter1**	**Iter 2**	**Iter 3**	**Iter 4**	**total iteration 1-4**
4	1	1	IH8	1	1	1	1	4
4	2	2	IH8	1	0	1	1	3
5	1	1	IH8	2	1	1	1	4
5	2	2	IH8	1	1	1	1	4
5	1	1	IH8	0	1	1	1	4
5	2	2	IH8	1	1	1	1	5
5	1	1	IH8	1	0	1	1	3
5	2	2	IH8	0	1	2	1	3
6	1	1	IH8	1	1	1	1	5
6	2	2	IH8	1	1		1	4
6	1	1	IH8	1	1	1	0	1
6	2	2	IH8	1	1	1	1	4
6	1	1	IH8	1	1	1	1	4
6	2	2	IH8	1	1	1	1	4
1	1	1	IH9	1	1	1	1	4
1	2	2	IH9	1	1	1	1	4
1	1	1	IH9	1	1	1	1	4
1	2	2	IH9	1	1	1	1	4
1	1	1	IH9	1	1	1	1	4
1	2	2	IH9	1	1	1	1	4
2	1	1	IH9	1	1	1	1	4
2	2	2	IH9	1	1	1	1	4
2	1	1	IH9	1	1	1	1	4
2	2	2	IH9	1	1	1	1	4
2	1	1	IH9	1	1	1	1	4
2	2	2	IH9	1	1	1	1	4

3	1	1	IH9	1	1	1	1	4
3	2	2	IH9	1	1	1	1	4
3	1	1	IH9	1	1	1	1	4
3	2	2	IH9	1	1	1	1	4
3	1	1	IH9	1	1	1	1	4
3	2	2	IH9	1	1	1	1	4
4	1	1	IH9	1	1	1	1	4
4	2	2	IH9	1	1	1	1	4
4	1	1	IH9	1	1	1	1	4
4	2	2	IH9	1	1	1	1	4
4	1	1	IH9	1	1	1	1	4
4	2	2	IH9	1	1	1	1	4
5	1	1	IH9	2	1	1	1	4
5	2	2	IH9	1	1	1	1	4
5	1	1	IH9	0	1	1	1	4
5	2	2	IH9	1	1	1	1	5
Partpant2	**Rig1-32**	**BM-EM2**	**event string**	**Iter1**	**Iter 2**	**Iter 3**	**Iter 4**	**total iteration 1-4**
5	2	2	IH9	1	1	1	1	3
6	1	1	IH9	1	1	1	1	4
6	2	2	IH9	1	1	1	1	4
6	1	1	IH9	1	1	1	1	4
6	2	2	IH9	1	1	1	1	4
6	1	1	IH9	0	1	1	1	4
6	2	2	IH9	0	1	1	1	4

B1. Consent form

R09/LJB/LJB746

Project Title: The Shape Assembly Test

Researcher: Lisa Bowers

Supervisor: Dr. Farshid Amirabdohallian (University Hertfordshire)

Dear Colleague,

The following is a consent form which consents to a controlled intervention with haptic testing equipment to complete a simple peg test. The consent will cover the following points:

I have received information about this research project.

I understand the purpose of the research project and my involvement in it.

I understand that I may withdraw from the research project at any stage.

I understand that my personal result will remain confidential and I wouldn't be indented if the information may be published.

I have been informed that might be taken pictures and videos during the study, which may be published.

I agree with the term above and indicate my agreement by signing here:

Name of participant:____

Date:_______________

Signature: _______________________________

Yours sincerely

Lisa Bowers (Lead research - haptics Esteem project)

B2 Raw SPSS Data - Chapter 6

Participant	Gender	Group	Hapticmode	Duration	ncoll
1	2	2	2	3.13	3
2	1	2	1	0.35	2
2	1	2	2	1.23	3
3	2	2	1	0.4	2
3	2	2	2	0.5	3
4	2	2	1	0.35	2
4	2	2	2	0.3	1
5	2	2	1	0.5	3
5	2	2	2	1.3	2
6	1	2	1	0.4	2
6	1	2	2	0.36	2
7	2	2	1	0.5	3
7	2	2	2	0.36	1
8	1	2	1	0.35	3
8	1	2	2	0.35	1
9	1	2	1	1.5	2
9	1	2	2	5	3
10	1	2	1	1.55	2
10	1	2	2	4.35	2
11	2	1	1	2	2
11	2	1	2	0.45	1
12	2	1	1	0.25	2
12	2	1	2	0.35	2
1	2	2	1	0.3	1
13	2	1	1	0.26	1
13	2	1	2	0.45	3
14	1	1	1	0.4	2
14	1	1	2	1.09	1
15	1	1	1	0.5	2
15	1	1	2	2.39	1
16	2	1	1	0.35	1
16	2	1	2	1.35	2
17	1	1	1	0.45	3
17	1	1	2	1.23	2
18	2	1	1	1.4	2
18	2	1	2	1.15	1
19	2	1	1	0.35	2
19	2	1	2	0.35	1
20	2	1	1	0.45	1
20	2	1	2	1.3	2

B3: pilot test feedback

- This appendix presents 3x design academics, 1x beta test session for 1 x day of testing for the Shape Assembly test.

Participant 1: "to engage with 3D models brings an entirely different dimension to the student's design concept thinking. Your interface offers students the simulation of 3D designed models in a virtual world… This tool has so much more potential for non-sighted learners who may now engage with models through touch."

Quantitative Raw

Staff No.	Duration (Mins)	Collisions
S1	7	4
S2	8	3
S3	9	5

B4 : Cohen's Kappa – Shape Assembly Test (Main)

Descriptor:

Cohen's kappa coefficient is a test statistic which determines the degree of agreement between two different evaluations from a response variable. The response variable must be in categorical form. The evaluations of the response variable are observed either by two different raters or by the same rater at two different times

1. Identify in title or abstract that interrater/intra rater reliability or agreement was investigated.
2. measurement device of interest explicitly. .
3. 3 provide a rationale for the study (if applicable). METHODS 6. Explain how the sample size was chosen.
4. State the determined number of raters, subjects/objects, and replicate observations. .

B5 Nvivo 21 Raw data (Shape Assembly Test)

Aggregate	Classification	Coverage	Number Of Coding Refer	Reference Number	Coded By Initials	Modified On

Node

Nodes\\Fit for purpose

Document

Internals\\Shape Assembly\\USER TEST EVALUATION

Aggregate	Classification	Coverage	Number Of Coding Refer	Reference Number	Coded By Initials	Modified On
No		0.0197	1			
				1	LJB	13/01/2018 10:08

No stress not at all

Internals\\Shape Assembly\\USER TEST EVALUATION

Aggregate	Classification	Coverage	Number Of Coding Refer	Reference Number	Coded By Initials	Modified On
No		0.2202	1			
				1	LJB	13/01/2018 10:12

As a designer I felt that this product has some way to go as the device itself was really heavy and took up some space. But as it offered so much interaction I would say using it through the OU would be great

Internals\\Shape Assembly\\USER TEST EVALUATION

Aggregate	Classification	Coverage	Number Of Coding Refer	Reference Number	Coded By Initials	Modified On
No		0.1217	2			
				1		

I performed well, and I want one!!

				2		13/01/2018 10:10

The interface was great got the idea of it all really quickly.

Internals\\Shape Assembly\\USER TEST EVALUATION

Aggregate	Classification	Coverage	Number Of Coding Refer	Reference Number	Coded By Initials	Modified On
No		0.1282	4			
				1		13/01/2018 09:53

It was satisfying accomplishing something which I had thought impossible/very difficult in a relatively easy manner

Aggre-gate	Classification	Coverage	Number Of Coding Refer...	Refer-ence Number	Coded By Initials	Modified On
				2	LJB	13/01/2018 09:54

Without the interface I can't conceive how the task could be accomplished on my own

				3	LJB	13/01/2018 09:54

Only other alternative would have been a sighted assistant to do all the work

				4	LJB	13/01/2018 09:55

Minimal stress, I have found using new software more frustrating than using the robot.

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0159	1			
				1	LJB	13/01/2018 10:01

Very easy indeed.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0689	1			
				1	LJB	13/01/2018 10:02

Using the device it felt the similar as holding a pen and writing on paper.

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0667	1			
				1	LJB	13/01/2018 10:03

It was very clear how to use the device, and for motoric disabilities could be useful for design purposes

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1114	2			
				1	LJB	13/01/2018 10:03

I think with the short training time I did ok to complete the task in roughly the same time as normal

				2	LJB	13/01/2018 10:04

The 'wand' or handle was a bit of an awkward angle/position.

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Nodes\\Fit for purpose\1

Document

Internals\\Shape Assembly\\

No		0.0021	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\Haptic TEST

No		0.0013	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0019	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No		0.0101	1			

				1	LJB	15/02/2018 13:15

USER TEST EVALUATION.

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0021	1			
				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0024	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0011	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0011	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0007	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0020	1			
				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0019	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0012	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0013	1			
				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Nodes\\Fit for purpose\10

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No		0.0485	1			

				1	LJB	15/02/2018 13:15

Number rank (0- 100) 0=poor 100=excellent.

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No		0.0305	1			
				1	LJB	15/02/2018 13:15

Number rank (0- 100) 0=poor 100=excellent.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0443	1			
				1	LJB	15/02/2018 13:15

Number rank (0- 100) 0=poor 100=excellent.

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No		0.0031	1			
				1	LJB	15/02/2018 13:15

Notes

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0474	1			
				1	LJB	15/02/2018 13:15

Number rank (0- 100) 0=poor 100=excellent.

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No 0.0559 1

1 LJB 15/02/2018 13:15

Number rank (0- 100) 0=poor 100=excellent.

Internals\\Shape Assembly\\USER TEST EVALUATION

No 0.0268 1

1 LJB 15/02/2018 13:15

Number rank (0- 100) 0=poor 100=excellent.

Internals\\Shape Assembly\\USER TEST EVALUATION

No 0.0268 1

1 LJB 15/02/2018 13:15

Number rank (0- 100) 0=poor 100=excellent.

Internals\\Shape Assembly\\USER TEST EVALUATION

No 0.0113 1

1 LJB 15/02/2018 13:15

1-100 (0=poor – 100 excellent)

Internals\\Shape Assembly\\USER TEST EVALUATION

No 0.0420 1

1 LJB 15/02/2018 13:15

Number rank (0- 100) 0=poor 100=excellent.

Internals\\Shape Assembly\\USER TEST EVALUATION

No 0.0465 1

1 LJB 15/02/2018 13:15

Number rank (0- 100) 0=poor 100=excellent.

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0440	1			
				1	LJB	15/02/2018 13:15

Number rank (0- 100) 0=poor 100=excellent.

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0420	1			
				1	LJB	15/02/2018 13:15

Number rank (0- 100) 0=poor 100=excellent.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0407	1			
				1	LJB	15/02/2018 13:15

Number rank (0- 100) 0=poor 100=excellent.

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0285	1			
				1	LJB	15/02/2018 13:15

Number rank (0- 100) 0=poor 100=excellent.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0311	1			
				1	LJB	15/02/2018 13:15

Number rank (0- 100) 0=poor 100=excellent.

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Nodes\\Fit for purpose\11

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No		0.0474	1			
				1	LJB	15/02/2018 13:15

Did you perform well using the haptic APP?

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No		0.0298	1			
				1	LJB	15/02/2018 13:15

Did you perform well using the haptic APP?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0433	1			
				1	LJB	15/02/2018 13:15

Did you perform well using the haptic APP?

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No		0.2618	1			
				1	LJB	15/02/2018 13:15

I felt that I was able to perform the task set with the apparatus without major issues though defining the shapes of objects was a little tricky and locating blocks that fell was also tricky as there were no clues given through the interface as to where. Also the sound became confused I believe when the pointer came too close to 2 objects at the same time. I believe this is that the software was playing multiple sound files simultaneously.

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0463	1			
				1	LJB	15/02/2018 13:15

Did you perform well using the haptic APP?

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0546	1			
				1	LJB	15/02/2018 13:15

Did you perform well using the haptic APP?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0262	1			
				1	LJB	15/02/2018 13:15

Did you perform well using the haptic APP?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0262	1			
				1	LJB	15/02/2018 13:15

Did you perform well using the haptic APP?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0017	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0411	1			
				1	LJB	15/02/2018 13:15

Did you perform well using the haptic APP?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0455	1			
				1	LJB	15/02/2018 13:15

Did you perform well using the haptic APP?

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0430	1			
				1	LJB	15/02/2018 13:15

Did you perform well using the haptic APP?

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0411	1			
				1	LJB	15/02/2018 13:15

Did you perform well using the haptic APP?

Internals\\Shape Assembly\\USER TEST EVALUATION

No	0.0398	1			
			1	LJB	15/02/2018 13:15

Did you perform well using the haptic APP?

Internals\\Shape Assembly\\USER TEST EVALUATION-

yes	0.0279	1			
			1	LJB	15/02/2018 13:15

Did you perform well using the haptic APP?

Internals\\Shape Assembly\\USER TEST EVALUATION

yes	0.0304	1			
			1	LJB	15/02/2018 13:15

Did you perform well using the haptic APP?

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Nodes\\Fit for purpose\12

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No	0.0345	1			
			1	LJB	15/02/2018 13:15

1-100 (0=poor – 100 excellent)

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

yes	0.0216	1			
			1	LJB	15/02/2018 13:15

1-100 (0=poor – 100 excellent)

Internals\\Shape Assembly\\USER TEST EVALUATION

yes	0.0315	1			
			1	LJB	15/02/2018 13:15

1-100 (0=poor – 100 excellent)

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No	0.0119	1			
			1	LJB	15/02/2018 13:15

Was the interface useful?

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No	0.0337	1			
			1	LJB	15/02/2018 13:15

No

No

Aggre-gate

No

No

No

Internals\\Shape Assembly\\USER TEST EVALUATION

No 0.1123 1

1 LJB 15/02/2018 13:15

It was satisfying accomplishing something which I had thought impossible/very difficult in a relatively easy manner. While the task was simple it was interesting to think what more challenging t asks might be accomplished with the robot. Moving from a mental picture to actually creating a prototype was satisfying.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0056	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0082	1			
				1	LJB	15/02/2018 13:15

55 NS1

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION kerry sighted

No		0.0058	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0056	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0054	1			
				1	LJB	15/02/2018 13:15

FS1

Internals\\Shape Assembly\\USER TEST EVALUATION-Daniel Hajas

No		0.0038	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATIONgreg

No		0.0041	1			
				1	LJB	15/02/2018 13:15

NS1

Aggre-gate	Classification	Coverage	Number Of Coding Refer...	Refer-ence Number	Coded By Initials	Modified On

Nodes\\Fit for purpose\14

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No		0.0021	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\Haptic TEST EVALUATION.Daniel Rivers

	No	0.0013	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

	No	0.0039	1			
				1	LJB	15/02/2018 13:15
65						

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

	No	0.0022	1			
				1	LJB	15/02/2018 13:15
80%						

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

	No	0.0042	1			
				1	LJB	15/02/2018 13:15
85						

Aggre- gate	Classification	Coverage	Number Of Coding Refer	Refer- ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

	No	0.0049	1			
				1	LJB	15/02/2018 13:15
90						

Internals\\Shape Assembly\\USER TEST EVALUATION Alex

No	0.0011	1			
			1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION Alex keable

No	0.0011	1			
			1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION Derek Naysmith

No	0.0102	1			
			1	LJB	15/02/2018 13:15

2 Was the interface useful?

Internals\\Shape Assembly\\USER TEST EVALUATION

No	0.0018	1			
			1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION jb

No	0.0020	1			
			1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0039	1			
				1	LJB	15/02/2018 13:15

90

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0012	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATIONgreg

No		0.0013	1			
				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Nodes\\Fit for purpose\15

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No		0.0151	1			
				1	LJB	15/02/2018 13:15

Number 50

Internals\\Shape Assembly\\Haptic TEST EVALUATION.Daniel Rivers

No		0.0088	1			
				1	LJB	15/02/2018 13:15

Number - 80

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1802	1			
				1	LJB	15/02/2018 13:15

Number Notes It was all very interesting. I performed well even though when under pressure my sisght re-duces. I felt as if there was no pressure to use the interface and I liked it.

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No		0.0031	1			
				1	LJB	15/02/2018 13:15

Notes

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0094	1			
				1	LJB	15/02/2018 13:15

Number

Aggre- gate	Classification	Coverage	Number Of Coding Refer	Refer- ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0534	1			
				1	LJB	15/02/2018 13:15

Number I performed well, and I want one!!

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0065	1			
				1	LJB	15/02/2018 13:15

Number 73

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0065	1			
				1	LJB	15/02/2018 13:15

Number 73

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0134	1			
				1	LJB	15/02/2018 13:15

1-100 (0=not useful-100=very useful)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0112	1			
				1	LJB	15/02/2018 13:15

Number 90

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0082	1			
				1	LJB	15/02/2018 13:15

Number

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0998	1			
				1	LJB	15/02/2018 13:15

Number I worked great with this device and the interface. My understanding and aims were clear to me

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0112	1			
				1	LJB	15/02/2018 13:15

Number 90

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0117	1			
				1	LJB	15/02/2018 13:15

Number - 95

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0025	1			
				1	LJB	15/02/2018 13:15

70

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0089	1			
				1	LJB	15/02/2018 13:15

Number - 80

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Nodes\\Fit for purpose\16

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No		0.0226	1			
				1	LJB	15/02/2018 13:15

Notes satisfactory

Internals\\Shape Assembly\\Haptic TEST EVALUATION.Daniel Rivers

Aggregate	Classification	Coverage	Number Of Coding References	Reference Number	Coded By Initials	Modified On
No		0.0440	1			
				1	LJB	15/02/2018 13:15

Notes – I felt as if I managed to use the device and APP well.

Internals\\Shape Assembly\\USER TEST EVALUATION

Aggregate	Classification	Coverage	Number Of Coding References	Reference Number	Coded By Initials	Modified On
No		0.0266	1			
				1	LJB	15/02/2018 13:15

Was the interface useful?

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

Aggregate	Classification	Coverage	Number Of Coding References	Reference Number	Coded By Initials	Modified On
No		0.3859	1			
				1	LJB	15/02/2018 13:15

I can see this being used to collaborate ideas over distance, especially amongst those with visual impairment. Descriptions are a subjective means of understanding and sometimes it is easier to actually feel something or to build a shape you may be describing. It might also be used to teach particularly specialised tasks to those that maybe required to work without appropriate lighting that their vision is impaired or lost. These may include delicate engineering adjustments on the sea bed, performing surgery on a patient and the power fails else dis-arming an explosive device where you cannot see the mechanisms delicate parts. Also in terms of training the

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

Aggregate	Classification	Coverage	Number Of Coding References	Reference Number	Coded By Initials	Modified On
No		0.2286	1			
				1	LJB	15/02/2018 13:15

Notes As a designer I felt that this product has some way to go as the device itself was really heavy and took up some space. But as it offered so much interaction I would say using it through the OU would be great.

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No 0.0086 1

1 LJB 15/02/2018 13:15

Notes

Internals\\Shape Assembly\\USER TEST EVALUATION

No 0.0041 1

1 LJB 15/02/2018 13:15

Notes

Internals\\Shape Assembly\\USER TEST EVALUATION

No 0.0041 1

1 LJB 15/02/2018 13:15

Notes

Internals\\Shape Assembly\\USER TEST EVALUATION

No 0.0017 1

1 LJB 15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No 0.1131 1

1 LJB 15/02/2018 13:15

Notes I soon got the hang of it, and was able to complete the task. At first I tried to push the Avatar through a block

Internals\\Shape Assembly\\USER TEST EVALUATION

No 0.1366 1

1 LJB 15/02/2018 13:15

Notes I would suggest everyone works with this app It was easy to use, easy to understand. It only took me a few minutes to use it

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0068	1			
				1	LJB	15/02/2018 13:15

Notes

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.1131	1			
				1	LJB	15/02/2018 13:15

Notes I soon got the hang of it, and was able to complete the task. At first I tried to push the Avatar through a block

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1015	1			
				1	LJB	15/02/2018 13:15

Notes – I enjoyed using the haptic app and I feel as though I could have performed better with more practice.

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0940	1			
				1	LJB	15/02/2018 13:15

I believe I performed well,as I could construct the shape required within 2 minutes without prior knowledge or extensive practice with the device.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0775	1			
				1	LJB	15/02/2018 13:15

Notes – I think with the short training time I did ok to complete the task in roughly the same time as normal.

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Nodes\\Fit for purpose\17

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No		0.0291	1			
				1	LJB	15/02/2018 13:15

Was the interface useful?

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No		0.0183	1			
				1	LJB	15/02/2018 13:15

Was the interface useful?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0374	1			
				1	LJB	15/02/2018 13:15

1-100 (0=not useful-100=very useful)

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No		0.0168	1			
				1	LJB	15/02/2018 13:15

Was the device easy to hold and use?

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0284	1			
				1	LJB	15/02/2018 13:15

Was the interface useful?

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0335	1			
				1	LJB	15/02/2018 13:15

Was the interface useful?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0447	1			
				1	LJB	15/02/2018 13:15

Yes given the time I had however I felt it would be better with more time

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0447	1			
				1	LJB	15/02/2018 13:15

Yes given the time I had however I felt it would be better with more time

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0014	1			
				1	LJB	15/02/2018 13:15

95

Internals\\Shape Assembly\\USER TEST EVALUATION Ian Roberts

No		0.0252	1			
				1	LJB	15/02/2018 13:15

Was the interface useful?

Internals\\Shape Assembly\\USER TEST EVALUATION jb

No		0.0279	1			
				1	LJB	15/02/2018 13:15

Was the interface useful?

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION kerry sighted

No		0.0264	1			
				1	LJB	15/02/2018 13:15

Was the interface useful?

Internals\\Shape Assembly\\USER TEST EVALUATION.ian sighted

No		0.0252	1			
				1	LJB	15/02/2018 13:15

Was the interface useful?

Internals\\Shape Assembly\\USER TEST EVALUATION

No	0.0244	1			
			1	LJB	15/02/2018 13:15

Was the interface useful?

Internals\\Shape Assembly\\USER TEST EVALUATION-

No	0.0171	1			
			1	LJB	15/02/2018 13:15

Was the interface useful?

Internals\\Shape Assembly\\USER TEST EVALUATION

No	0.0186	1			
			1	LJB	15/02/2018 13:15

Was the interface useful?

Aggre- gate	Classification	Coverage	Number Of Coding Refer	Refer- ence Number	Coded By Initials	Modified On

Nodes\\Fit for purpose\18

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No 0.0409 1

1 LJB 15/02/2018 13:15

1-100 (0=not useful-100=very useful)

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No 0.0257 1

1 LJB 15/02/2018 13:15

1-100 (0=not useful-100=very useful)

Internals\\Shape Assembly\\USER TEST EVALUATION

No 0.0049 1

1 LJB 15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No 0.0225 1

1 LJB 15/02/2018 13:15

1-100 (0= not easy – 100= very useful) NS1 Number

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No 0.0400 1

1 LJB 15/02/2018 13:15

1-100 (0=not useful-100=very useful)

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0472	1			
				1	LJB	15/02/2018 13:15

1-100 (0=not useful-100=very useful)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0161	1			
				1	LJB	15/02/2018 13:15

Was the interface useful?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0161	1			
				1	LJB	15/02/2018 13:15

Was the interface useful?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1194	1			
				1	LJB	15/02/2018 13:15

Without the interface I can't conceive how the task could be accomplished on my own. Only other alternative would have been a sighted assistant to do all the work. The presence of the interface opens up exciting poten-tial allowing VI students to participate more in design exercises in a variety of modules and beyond into em

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0355	1			
				1	LJB	15/02/2018 13:15

1-100 (0=not useful-100=very useful)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0393	1			

				1	LJB	15/02/2018 13:15

1-100 (0=not useful-100=very useful)

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0371	1			
				1	LJB	15/02/2018 13:15

1-100 (0=not useful-100=very useful)

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0355	1			
				1	LJB	15/02/2018 13:15

1-100 (0=not useful-100=very useful)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0344	1			
				1	LJB	15/02/2018 13:15

1-100 (0=not useful-100=very useful)

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0241	1			
				1	LJB	15/02/2018 13:15

1-100 (0=not useful-100=very useful)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0262	1			
				1	LJB	15/02/2018 13:15

1-100 (0=not useful-100=very useful)

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Nodes\\Fit for purpose\19

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No		0.0053	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No		0.0033	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0039	1			
				1	LJB	15/02/2018 13:15

80

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No		0.0026	1			
				1	LJB	15/02/2018 13:15

100%

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0052	1			
				1	LJB	15/02/2018 13:15

NS1

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0062	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0226	1			
				1	LJB	15/02/2018 13:15

1-100 (0=not useful-100=very useful)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0226	1			

				1	LJB	15/02/2018 13:15

1-100 (0=not useful-100=very useful)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0141	1			
				1	LJB	15/02/2018 13:15

3 Was the device easy to hold and use?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0046	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0072	1			
				1	LJB	15/02/2018 13:15

85NS1

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0048	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION.ian sighted

No		0.0046	1			

				1	LJB	15/02/2018 13:15
NS1						

Internals\\Shape Assembly\\USER TEST EVALUATIONAndrew

No		0.0045	1			
				1	LJB	15/02/2018 13:15
FS1						

Internals\\Shape Assembly\\USER TEST EVALUATION-Daniel Hajas

No		0.0031	1			
				1	LJB	15/02/2018 13:15
NS1						

Internals\\Shape Assembly\\USER TEST EVALUATIONgreg

No		0.0034	1			
				1	LJB	15/02/2018 13:15
NS1						

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Nodes\\Fit for purpose\2

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No 0.0248 1

1 LJB 15/02/2018 13:15

USER TEST EVALUATION.

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No 0.0230 1

1 LJB 15/02/2018 13:15

Daniel Rivers - TEST EVALUATION.

Internals\\Shape Assembly\\USER TEST EVALUATION

No 0.0226 1

1 LJB 15/02/2018 13:15

USER TEST EVALUATION.

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No 0.0008 1

1 LJB 15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No 0.0242 1

1 LJB 15/02/2018 13:15

USER TEST EVALUATION.

15/02/2018 13:37

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0285	1			
				1	LJB	15/02/2018 13:15

USER TEST EVALUATION.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0137	1			
				1	LJB	15/02/2018 13:15

USER TEST EVALUATION.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0137	1			
				1	LJB	15/02/2018 13:15

USER TEST EVALUATION.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0081	1			
				1	LJB	15/02/2018 13:15

USER TEST EVALUATION.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0215	1			
				1	LJB	15/02/2018 13:15

USER TEST EVALUATION.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0238	1			

				1	LJB	15/02/2018 13:15

USER TEST EVALUATION.

Aggre- gate	Classification	Coverage	Number Of Coding Refer	Refer- ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0225	1			
				1	LJB	15/02/2018 13:15

USER TEST EVALUATION.

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0215	1			
				1	LJB	15/02/2018 13:15

USER TEST EVALUATION.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0208	1			
				1	LJB	15/02/2018 13:15

USER TEST EVALUATION.

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0146	1			
				1	LJB	15/02/2018 13:15

USER TEST EVALUATION.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0159	1			

				1	LJB	15/02/2018 13:15

USER TEST EVALUATION.

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Nodes\\Fit for purpose\20

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No		0.0129	1			
				1	LJB	15/02/2018 13:15

Number 75

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No		0.0088	1			
				1	LJB	15/02/2018 13:15

Number - 60

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0995	1			
				1	LJB	15/02/2018 13:15

Number 65 I wanted to tweak the interface but its amazng to think I completed the task in a short time

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No		0.0031	1			
				1	LJB	15/02/2018 13:15

Notes

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0410	1			
				1	LJB	15/02/2018 13:15

Number I found it useful, thanks Lisa

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0881	1			
				1	LJB	15/02/2018 13:15

Number The interface was great got the idea of it all really quickly.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0029	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0029	1			

				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0141	1			
				1	LJB	15/02/2018 13:15

1-100 (0= not easy – 100= very useful)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0102	1			
				1	LJB	15/02/2018 13:15

Number 95

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1118	1			
				1	LJB	15/02/2018 13:15

Number The interface was very clever, I really enjoyed myself and the noises and movement was interwssting

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0039	1			
				1	LJB	15/02/2018 13:15

75

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0102	1			

				1	LJB	15/02/2018 13:15

Number 95

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0135	1			
				1	LJB	15/02/2018 13:15

Number – 100

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0025	1			
				1	LJB	15/02/2018 13:15

70

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0089	1			
				1	LJB	15/02/2018 13:15

Number - 70

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Nodes\\Fit for purpose\21

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No	0.0701	1			
			1	LJB	15/02/2018 13:15

Notes useful, could have had auditory feedback for fixed block

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No	0.0996	1			
			1	LJB	15/02/2018 13:15

Notes – In its current form it serves well as a testing tool, but its usefulness will only be established when being used for more than testing

Internals\\Shape Assembly\\USER TEST EVALUATION

No	0.0068	1			
			1	LJB	15/02/2018 13:15

Notes

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No	0.0305	1			
			1	LJB	15/02/2018 13:15

Yes - sound was extremely helpful in addition to the device itself.

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No	0.0073	1			
			1	LJB	15/02/2018 13:15

Notes

15/02/2018 13:37

Aggre- gate	Classification	Coverage	Number Of Coding Refer	Refer- ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0086	1			
				1	LJB	15/02/2018 13:15

Notes

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0065	1			
				1	LJB	15/02/2018 13:15

Number 61

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0065	1			
				1	LJB	15/02/2018 13:15

Number 61

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0017	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1010	1			
				1	LJB	15/02/2018 13:15

Notes It would be nice to be able to drop the blocks by a control on the robot, rather than the shift key.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0072	1			

				1	LJB	15/02/2018 13:15

Notes

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1771	1			
				1	LJB	15/02/2018 13:15

Number I could see how this device and interface could be useful to all people, not just sighted which is amaz-ing to think about. Someone thinking of us slight imapired is amazing

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.1010	1			
				1	LJB	15/02/2018 13:15

Notes It would be nice to be able to drop the blocks by a control on the robot, rather than the shift key.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0571	1			
				1	LJB	15/02/2018 13:15

Notes – I found the interface very easy to navigate and use.

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.1391	1			
				1	LJB	15/02/2018 13:15

It was very clear how to use the device, and for motoric disabilities could be useful for design purposes. Given you can see the screen or have audio guidance on location of blocks, this could be a very useful device.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1328	1			

				1	LJB	15/02/2018 13:15

Notes – The robot was tricky to get use to originally and sometimes it felt like it got too close to itself when going forward, but this could be because it is the first time I have used it.

Aggregate	Classification	Coverage	Number Of Coding Refer	Reference Number	Coded By Initials	Modified On

Nodes\\Fit for purpose\22

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No		0.0409	1			
				1	LJB	15/02/2018 13:15

Was the device easy to hold and use?

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No		0.0257	1			
				1	LJB	15/02/2018 13:15

Was the device easy to hold and use?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0374	1			
				1	LJB	15/02/2018 13:15

Was the device easy to hold and use?

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No		0.0345	1			
				1	LJB	15/02/2018 13:15

Did you become mentally stressed or frustrated at any time during the trial?

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0400	1			
				1	LJB	15/02/2018 13:15

Was the device easy to hold and use?

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0472	1			
				1	LJB	15/02/2018 13:15

Was the device easy to hold and use?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0041	1			
				1	LJB	15/02/2018 13:15

Notes

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0041	1			

				1	LJB	15/02/2018 13:15

Notes

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0014	1			
				1	LJB	15/02/2018 13:15

90

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0355	1			
				1	LJB	15/02/2018 13:15

Was the device easy to hold and use?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0393	1			
				1	LJB	15/02/2018 13:15

Was the device easy to hold and use?

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0068	1			
				1	LJB	15/02/2018 13:15

Notes

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0355	1			

				1	LJB	15/02/2018 13:15

Was the device easy to hold and use?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0344	1			
				1	LJB	15/02/2018 13:15

Was the device easy to hold and use?

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0241	1			
				1	LJB	15/02/2018 13:15

Was the device easy to hold and use?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0262	1			
				1	LJB	15/02/2018 13:15

Was the device easy to hold and use?

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Nodes\\Fit for purpose\23

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No 0.0431 1

1 LJB 15/02/2018 13:15

1-100 (0= not easy – 100= very useful)

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No 0.0271 1

1 LJB 15/02/2018 13:15

1-100 (0= not easy – 100= very useful)

Internals\\Shape Assembly\\USER TEST EVALUATION

No 0.0394 1

1 LJB 15/02/2018 13:15

1-100 (0= not easy – 100= very useful)

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No 0.0190 1

1 LJB 15/02/2018 13:15

1-100(0= very stressed-100=no stress) NS1

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No 0.0421 1

1 LJB 15/02/2018 13:15

1-100 (0= not easy – 100= very useful)

15/02/2018 13:37

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0496	1			
				1	LJB	15/02/2018 13:15

1-100 (0= not easy – 100= very useful)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0805	1			
				1	LJB	15/02/2018 13:15

Can't remember too much but it seemed ok. Felt the viewpoints could be improved but probably won't help those with visual impairments

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0805	1			
				1	LJB	15/02/2018 13:15

Can't remember too much but it seemed ok. Felt the viewpoints could be improved but probably won't help those with visual impairments

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.2562	1			
				1	LJB	15/02/2018 13:15

Found I had few problems holding and using the device. Initially it seemed strange but soon I became confident moving the pointer round. Returning the pointer into its rest position provided the only problem as it required a bit of force compared to the easy movement. At one point the movement appeared to stick and this proved challenging until I was prompted what to do. Perhaps an audible clue, actual words, could be built in to assist in this situation. Like much access technology you might want the user to be able to select the level of audible

Internals\\Shape Assembly\\USER TEST EVALUATION Ian Roberts

No		0.0374	1			
				1	LJB	15/02/2018 13:15

1-100 (0= not easy – 100= very useful)

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0445	1			
				1	LJB	15/02/2018 13:15

1-100 (0= not easy – 100= very useful) 90

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0371	1			
				1	LJB	15/02/2018 13:15

Was the device easy to hold and use?

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0374	1			
				1	LJB	15/02/2018 13:15

1-100 (0= not easy – 100= very useful)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0362	1			
				1	LJB	15/02/2018 13:15

1-100 (0= not easy – 100= very useful)

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0254	1			
				1	LJB	15/02/2018 13:15

1-100 (0= not easy – 100= very useful)

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0276	1			
				1	LJB	15/02/2018 13:15

1-100 (0= not easy – 100= very useful)

Nodes\\Fit for purpose\24

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No		0.0053	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No		0.0033	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0049	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No		0.0044	1			
				1	LJB	15/02/2018 13:15

Number

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0052	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0062	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0226	1			
				1	LJB	15/02/2018 13:15

Was the device easy to hold and use?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0226	1			
				1	LJB	15/02/2018 13:15

Was the device easy to hold and use?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0283	1			
				1	LJB	15/02/2018 13:15

4 Did you become mentally stressed or frustrated at any time during the trial?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0046	1			
				1	LJB	15/02/2018 13:15

NS1

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0051	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No	0.0391	1			
			1	LJB	15/02/2018 13:15

1-100 (0= not easy – 100= very useful)

Internals\\Shape Assembly\\USER TEST EVALUATION.

No	0.0046	1			
			1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No	0.0045	1			
			1	LJB	15/02/2018 13:15

FS1

Internals\\Shape Assembly\\USER TEST EVALUATION-

No	0.0031	1			
			1	LJB	15/02/2018 13:15

NS1

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0034	1			
				1	LJB	15/02/2018 13:15

NS1

Nodes\\Fit for purpose\25

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No		0.0129	1			
				1	LJB	15/02/2018 13:15

Number 90

Internals\\Shape Assembly\\Haptic TEST EVALUATION.Daniel Rivers

No		0.0088	1			
				1	LJB	15/02/2018 13:15

Number - 90

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0266	1			
				1	LJB	15/02/2018 13:15

Number I would say so yes

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No		0.0026	1			
				1	LJB	15/02/2018 13:15

100%

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0084	1			
				1	LJB	15/02/2018 13:15

Number

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0099	1			
				1	LJB	15/02/2018 13:15

Number

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0238	1			
				1	LJB	15/02/2018 13:15

1-100 (0= not easy – 100= very useful)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0238	1			
				1	LJB	15/02/2018 13:15

1-100 (0= not easy – 100= very useful)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0138	1			

				1	LJB	15/02/2018 13:15

1-100(0= very stressed-100=no stress)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0112	1			
				1	LJB	15/02/2018 13:15

Number 100

Aggre-gate	Classification	Coverage	Number Of Coding Refer...	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0134	1			
				1	LJB	15/02/2018 13:15

Number EASY

Internals\\Shape Assembly\\USER TEST EVALUATION kerry sighted

No		0.0048	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION.ian sighted

No		0.0112	1			
				1	LJB	15/02/2018 13:15

Number 100

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0117	1			

				1	LJB	15/02/2018 13:15

Number -100

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0025	1			
				1	LJB	15/02/2018 13:15

95

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0089	1			
				1	LJB	15/02/2018 13:15

Number - 70

Nodes\\Fit for purpose\26

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Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No		0.0949	1			
				1	LJB	15/02/2018 13:15

Notes buttons on end of pen too close together, could result in pressing wrong button

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No		0.1613	1			
				1	LJB	15/02/2018 13:15

Notes – Yes the device was easy to hold and intuitive to use. I was impressed by the feel of the boundaries in the APP when converted to resistance in the device. Being able to feel the weight of the object was also a pleas-

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0068	1			
				1	LJB	15/02/2018 13:15

Notes

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No		0.0031	1			
				1	LJB	15/02/2018 13:15

Notes

Aggregate	Classification	Coverage	Number Of Coding Refer	Reference Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0073	1			
				1	LJB	15/02/2018 13:15

Notes

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0086	1			

				1	LJB	15/02/2018 13:15

Notes

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0029	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0029	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0017	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0243	1			
				1	LJB	15/02/2018 13:15

Notes Very easy indeed.

Aggre- gate	Classification	Coverage	Number Of Coding Refer	Refer- ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0072	1			

				1	LJB	15/02/2018 13:15

Notes

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0166	1			
				1	LJB	15/02/2018 13:15

Number ALL easy

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0243	1			
				1	LJB	15/02/2018 13:15

Very easy indeed.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0779	1			
				1	LJB	15/02/2018 13:15

Notes – Using the device it felt the simular as holding a pen and writing on paper.

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0991	1			
				1	LJB	15/02/2018 13:15

Very easy to use, and hold,the only restriction that I felt is not seeing the screen. If I saw the screen, I could create the object much faster I expect.

Aggregate	Classification	Coverage	Number Of Coding Refer	Reference Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0975	1			
				1	LJB	15/02/2018 13:15

Notes – The 'wand' or handle was a bit of an awkward angle/position. I would have personally found something I could grip as a fist easier.

Nodes\\Fit for purpose\27

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Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No 0.0841 1

1 LJB 15/02/2018 13:15

Did you become mentally stressed or frustrated at any time during the trial?

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No 0.0528 1

1 LJB 15/02/2018 13:15

Did you become mentally stressed or frustrated at any time during the trial?

Internals\\Shape Assembly\\USER TEST EVALUATION

No 0.0768 1

1 LJB 15/02/2018 13:15

Did you become mentally stressed or frustrated at any time during the trial?

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No 0.0053 1

1 LJB 15/02/2018 13:15

Not at all

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0821	1			
				1	LJB	15/02/2018 13:15

Did you become mentally stressed or frustrated at any time during the trial?

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0968	1			
				1	LJB	15/02/2018 13:15

Did you become mentally stressed or frustrated at any time during the trial?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0065	1			
				1	LJB	15/02/2018 13:15

Number 85

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0065	1			
				1	LJB	15/02/2018 13:15

Number 85

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0017	1			
				1	LJB	15/02/2018 13:15

95

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0729	1			
				1	LJB	15/02/2018 13:15

Did you become mentally stressed or frustrated at any time during the trial?

Aggre-gate	Classification	Coverage	Number Of Coding Refer...	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0807	1			
				1	LJB	15/02/2018 13:15

Did you become mentally stressed or frustrated at any time during the trial?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0068	1			
				1	LJB	15/02/2018 13:15

Notes

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0729	1			
				1	LJB	15/02/2018 13:15

Did you become mentally stressed or frustrated at any time during the trial?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0707	1			
				1	LJB	15/02/2018 13:15

Did you become mentally stressed or frustrated at any time during the trial?

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0495	1			
				1	LJB	15/02/2018 13:15

Did you become mentally stressed or frustrated at any time during the trial?

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0539	1			
				1	LJB	15/02/2018 13:15

Did you become mentally stressed or frustrated at any time during the trial?

Nodes\\Fit for purpose\28

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Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No		0.0420	1			
				1	LJB	15/02/2018 13:15

1-100(0= very stressed-100=no stress)

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No		0.0264	1			
				1	LJB	15/02/2018 13:15

1-100(0= very stressed-100=no stress)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0384	1			
				1	LJB	15/02/2018 13:15

1-100(0= very stressed-100=no stress)

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On
No		0.0469	1			
				1	LJB	15/02/2018 13:15

Did you become physically fatigued or stressed throughout any of the test with the APP or haptic device?

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On
No		0.0410	1			
				1	LJB	15/02/2018 13:15

1-100(0= very stressed-100=no stress)

Internals\\Shape Assembly\\USER TEST EVALUATION

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On
No		0.0484	1			
				1	LJB	15/02/2018 13:15

1-100(0= very stressed-100=no stress)

Internals\\Shape Assembly\\USER TEST EVALUATION

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On
No		0.0041	1			
				1	LJB	15/02/2018 13:15

Notes

Internals\\Shape Assembly\\USER TEST EVALUATION

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On
No		0.0041	1			
				1	LJB	15/02/2018 13:15

Notes

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0751	1			
				1	LJB	15/02/2018 13:15

Minimal stress, I have found using new software more frustrating than using the robot. Providing a test drive with sighted assistance is very important as without this it would be very easy to become stressed.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0364	1			
				1	LJB	15/02/2018 13:15

1-100(0= very stressed-100=no stress)

Aggre-gate	Classification	Coverage	Number Of Coding Refer...	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0434	1			
				1	LJB	15/02/2018 13:15

1-100(0= very stressed-100=no stress) 85

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0763	1			
				1	LJB	15/02/2018 13:15

Did you become mentally stressed or frustrated at any time during the trial?

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0364	1			
				1	LJB	15/02/2018 13:15

1-100(0= very stressed-100=no stress)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0353	1			
				1	LJB	15/02/2018 13:15

1-100(0= very stressed-100=no stress)

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0247	1			
				1	LJB	15/02/2018 13:15

1-100(0= very stressed-100=no stress)

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0269	1			
				1	LJB	15/02/2018 13:15

1-100(0= very stressed-100=no stress)

Nodes\\Fit for purpose\29

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No		0.0053	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\Haptic TEST EVALUATION.Daniel Rivers

No		0.0033	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0049	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No		0.0296	1			
				1	LJB	15/02/2018 13:15

1-100 (0=very stressed and fatigued – 100= no stress or fatique)

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0052	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0062	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1510	1			
				1	LJB	15/02/2018 13:15

Felt the device was ergonomically designed and could cover a range of positions and angles

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1510	1			
				1	LJB	15/02/2018 13:15

Felt the device was economically designed and could cover a range of positions and angles however I felt fur-
ther hardware is required as I had to use the keyboard to change a view point. Again this may not be a problem

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0386	1			
				1	LJB	15/02/2018 13:15

5 Did you become physically fatigued or stressed throughout any of the test with the APP or haptic device?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0046	1			
				1	LJB	15/02/2018 13:15

NS1

Aggregate	Classification	Coverage	Number Of Coding Refer	Reference Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0051	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No	0.0381	1			
			1	LJB	15/02/2018 13:15

1-100(0= very stressed-100=no stress)

Internals\\Shape Assembly\\USER TEST EVALUATION.

No	0.0046	1			
			1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No	0.0045	1			
			1	LJB	15/02/2018 13:15

FS1

Internals\\Shape Assembly\\USER TEST EVALUATION-

No	0.0031	1			
			1	LJB	15/02/2018 13:15

NS1

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No 0.0034 1

1 LJB 15/02/2018 13:15

NS1

Nodes\\Fit for purpose\3

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No 0.0021 1

1 LJB 15/02/2018 13:15

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No 0.0013 1

1 LJB 15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No 0.0019 1

1 LJB 15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No 0.0088 1

1 LJB 15/02/2018 13:15

Question User test

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0021	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0024	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0011	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0011	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0007	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0020	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0019	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0099	1			
				1	LJB	15/02/2018 13:15

ANDREW.FS

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0012	1			
				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0013	1			
				1	LJB	15/02/2018 13:15

Nodes\\Fit for purpose\30

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No		0.0021	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\Haptic TEST EVALUATION

No		0.0013	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0049	1			
				1	LJB	15/02/2018 13:15

100

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No		0.0031	1			
				1	LJB	15/02/2018 13:15

100%

Aggre- gate	Classification	Coverage	Number Of Coding Refer	Refer- ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0021	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0024	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0465	1			
				1	LJB	15/02/2018 13:15

Did you become mentally stressed or frustrated at any time during the trial?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0465	1			
				1	LJB	15/02/2018 13:15

Did you become mentally stressed or frustrated at any time during the trial?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0233	1			
				1	LJB	15/02/2018 13:15

1-100 (0=very stressed and fatigued – 100= no stress or fatique)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0020	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0048	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0190	1			
				1	LJB	15/02/2018 13:15

Number Notes – 100

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0012	1			
				1	LJB	15/02/2018 13:15

Aggre- gate	Classification	Coverage	Number Of Coding Refer	Refer- ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0013	1			

Nodes\\Fit for purpose\31

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No		0.0086	1			
				1	LJB	15/02/2018 13:15

Number

Internals\\Shape Assembly\\Haptic TEST EVALUATION

No		0.0088	1			
				1	LJB	15/02/2018 13:15

Number - 20

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0344	1			
				1	LJB	15/02/2018 13:15

Number Notes No stress not at all

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0147	1			
				1	LJB	15/02/2018 13:15

Number Notes

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0173	1			
				1	LJB	15/02/2018 13:15

Number Notes

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0232	1			
				1	LJB	15/02/2018 13:15

1-100(0= very stressed-100=no stress)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0232	1			
				1	LJB	15/02/2018 13:15

1-100(0= very stressed-100=no stress)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0017	1			
				1	LJB	15/02/2018 13:15

100

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0112	1			
				1	LJB	15/02/2018 13:15

Number 100

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0144	1			
				1	LJB	15/02/2018 13:15

Number Notes

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0019	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No	0.0112	1			
			1	LJB	15/02/2018 13:15

Number 100

Internals\\Shape Assembly\\USER TEST EVALUATION

No	0.0616	1			
			1	LJB	15/02/2018 13:15

No, I did not become mentally stressed or frustrated at any time.

Internals\\Shape Assembly\\USER TEST EVALUATION-

No	0.2350	1			
			1	LJB	15/02/2018 13:15

85 not very stressful,…. while holding the pen in the right hand and clearly feeling a virtual wall, BUT the left hand did not feel anything when trying to find the wall on the table.

Internals\\Shape Assembly\\USER TEST EVALUATION

No	0.0089	1			
			1	LJB	15/02/2018 13:15

Number - 20

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Nodes\\Fit for purpose\32

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No	0.0636	1			
			1	LJB	15/02/2018 13:15

Notes no but felt a failure not achieving more quickly

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No	0.1532	1			
			1	LJB	15/02/2018 13:15

Notes – Not stressed but sometimes frustrated when I couldn't pick up the block. As discussed on the day, I think being sighted in this scenario was actually a hindrance.

Internals\\Shape Assembly\\USER TEST EVALUATION

No	0.1684	1			
			1	LJB	15/02/2018 13:15

Did you become physically fatigued or stressed throughout any of the test with the APP or haptic device? 1-100 (0=very stressed and fatigued – 100= no stress or fatigue)

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No	0.1801	1			
			1	LJB	15/02/2018 13:15

Did you become physically fatigued or stressed throughout any of the test with the APP or haptic device? 1-100 (0=very stressed and fatigued – 100= no stress or fatigue)

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No	0.2124	1			
			1	LJB	15/02/2018 13:15

Did you become physically fatigued or stressed throughout any of the test with the APP or haptic device? 1-100 (0=very stressed and fatigued – 100= no stress or fatigue)

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0029	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0029	1			
				1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1428	1			
				1	LJB	15/02/2018 13:15

No physical stress at all. In real use would want an adjustable computer chair to ensure sitting at a comfortable height relative to the robot. Perhaps activate voice recognition on computer so could simply ask for 'next' to get next block as opposed to hitting space bar. This in itself was not difficult but could imagine some with dex

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0336	1			
				1	LJB	15/02/2018 13:15

Notes I had no stress what so ever

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1801	1			
				1	LJB	15/02/2018 13:15

Did you become physically fatigued or stressed throughout any of the test with the APP or haptic device? 85 1-100 (0=very stressed and fatigued – 100= no stress or fatigue) No

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0136	1			
				1	LJB	15/02/2018 13:15

Number Notes

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0336	1			
				1	LJB	15/02/2018 13:15

Notes I had no stress what so ever

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1550	1			
				1	LJB	15/02/2018 13:15

Did you become physically fatigued or stressed throughout any of the test with the APP or haptic device? 1-100 (0=very stressed and fatigued – 100= no stress or fatigue)

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.1086	1			
				1	LJB	15/02/2018 13:15

Did you become physically fatigued or stressed throughout any of the test with the APP or haptic device? 1-100 (0=very stressed and fatigued – 100= no stress or fatigue)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1259	1			
				1	LJB	15/02/2018 13:15

Notes – Not really, the only issue was that the final block could flip over so easily, it did make me want to continue flipping it until it was back in the correct position though.

Nodes\\Fit for purpose\33

Document

Internals\\Shape Assembly\\

No		0.1844	1			
				1	LJB	15/02/2018 13:15

Did you become physically fatigued or stressed throughout any of the test with the APP or haptic device? 1-100 (0=very stressed and fatigued – 100= no stress or fatigue)

Aggregate	Classification	Coverage	Number Of Coding Refer	Reference Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No		0.1159	1			
				1	LJB	15/02/2018 13:15

Did you become physically fatigued or stressed throughout any of the test with the APP or haptic device? 1-100 (0=very stressed and fatigued – 100= no stress or fatigue)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0019	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0021	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0024	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0011	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0011	1			
				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0007	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1599	1			
				1	LJB	15/02/2018 13:15

Did you become physically fatigued or stressed throughout any of the test with the APP or haptic device? 1-100 (0=very stressed and fatigued – 100= no stress or fatigue)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0020	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1673	1			
				1	LJB	15/02/2018 13:15

Did you become physically fatigued or stressed throughout any of the test with the APP or haptic device? 1-100 (0=very stressed and fatigued – 100= no stress or fatigue)

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.1599	1			
				1	LJB	15/02/2018 13:15

Did you become physically fatigued or stressed throughout any of the test with the APP or haptic device? 1-100 (0=very stressed and fatigued – 100= no stress or fatigue)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0045	1			
				1	LJB	15/02/2018 13:15

FS1

Aggregate	Classification	Coverage	Number Of Coding Refer	Reference Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0012	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No	0.1183	1			
			1	LJB	15/02/2018 13:15

Did you become physically fatigued or stressed throughout any of the test with the APP or haptic device? 1-100 (0=very stressed and fatigued – 100= no stress or fatigue)

Nodes\\Fit for purpose\34

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No	0.0021	1			
			1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No	0.0033	1			
			1	LJB	15/02/2018 13:15

NS1

Internals\\Shape Assembly\\USER TEST EVALUATION

No	0.0019	1			
			1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0021	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0024	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0101	1			
				1	LJB	15/02/2018 13:15

Number 90 Notes

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0101	1			
				1	LJB	15/02/2018 13:15

Number 90 Notes

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0570	1			
				1	LJB	15/02/2018 13:15

Sorry but I found working in the original table problematic so I removed it. Using the Tab or cursor keys was not navigating me consistantly through the table.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0018	1			

				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0020	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0019	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION-Daniel Hajas

No		0.0012	1			

				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0013	1			
				1	LJB	15/02/2018 13:15

Nodes\\Fit for purpose\35

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No		0.0021	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\Haptic TEST EVALUATION.Daniel Rivers

No		0.0013	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0019	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0021	1			
				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0024	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION Alex

No		0.0477	1			
				1	LJB	15/02/2018 13:15

I found it frustrating at the start but this subsided once used to the device

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0477	1			

				1	LJB	15/02/2018 13:15

I found it frustrating at the start but this subsided once used to the device

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0010	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION Ian Roberts

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION jb

No		0.0020	1			
				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0019	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0018	1			

				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0045	1			
				1	LJB	15/02/2018 13:15

100

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0158	1			
				1	LJB	15/02/2018 13:15

95 Not stressed at all.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0013	1			
				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Nodes\\Fit for purpose\36

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No	0.0043	1			
			1	LJB	15/02/2018 13:15

no

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No	0.0013	1			
			1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No	0.0019	1			
			1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No	0.0021	1			
			1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No	0.0024	1			
			1	LJB	15/02/2018 13:15

15/02/2018 13:37

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1020	1			
				1	LJB	15/02/2018 13:15

Did you become physically fatigued or stressed throughout any of the test with the APP or haptic device? 1-100 (0=very stressed and fatigued – 100= no stress or fatigue)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1020	1			
				1	LJB	15/02/2018 13:15

Did you become physically fatigued or stressed throughout any of the test with the APP or haptic device? 1-100 (0=very stressed and fatigued – 100= no stress or fatigue)

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0056	1			
				1	LJB	15/02/2018 13:15

100

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0020	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0362	1			
				1	LJB	15/02/2018 13:15

Nope, want to try it all again soon

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0056	1			

				1	LJB	15/02/2018 13:15

100

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0480	1			
				1	LJB	15/02/2018 13:15

I did not suffer from fatigue throughout the test.

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0012	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0089	1			
				1	LJB	15/02/2018 13:15

Number – 10

Nodes\\Fit for purpose\37

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No		0.0021	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No		0.0081	1			
				1	LJB	15/02/2018 13:15

Number - 0

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0011	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0011	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0757	1			
				1	LJB	15/02/2018 13:15

I cannot think of anything that was to be stressed about or make you fatigued.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0020	1			

				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0019	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0757	1			
				1	LJB	15/02/2018 13:15

I cannot think of anything that was to be stressed about or make you fatigued.

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATIONgreg

No		0.0754	1			
				1	LJB	15/02/2018 13:15

Notes – Not really, I only used the device for 5 minutes, was not long enough to cause any sort of fatigue.

Nodes\\Fit for purpose\38

Document

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No		0.0508	1			
				1	LJB	15/02/2018 13:15

Notes – Nothing to note here – The device and APP were both easy to use.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0011	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0011	1			
				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0020	1			

				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0013	1			
				1	LJB	15/02/2018 13:15

Nodes\\Fit for purpose\39

Document

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No		0.0013	1			
				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0065	1			

1 LJB 15/02/2018 13:15

Number 90

Internals\\Shape Assembly\\USER TEST EVALUATION

No 0.0065 1

1 LJB 15/02/2018 13:15

Number 90

Internals\\Shape Assembly\\USER TEST EVALUATION

No 0.0020 1

1 LJB 15/02/2018 13:15

Nodes\\Fit for purpose\4

Document

Internals\\Shape Assembly

No 0.0021 1

1 LJB 15/02/2018 13:15

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No 0.0013 1

1 LJB 15/02/2018 13:15

15/02/2018 13:37

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0019	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No		0.0035	1			
				1	LJB	15/02/2018 13:15

code

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0021	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0024	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0011	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0011	1			

				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0007	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0020	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0019	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0018	1			

				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0012	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0013	1			
				1	LJB	15/02/2018 13:15

Nodes\\Fit for purpose\40

Document

Internals\\Shape Assembly\\USER TEST EVALUATION Alex

No		0.2304	1			
				1	LJB	15/02/2018 13:15

While I found the device nice to use I felt the app could be more polished but this I guess is expected for a prototype. The only concern I had is that there are real RSI risks from using a device and app such as this for long periods of time. As I only used this for a short period of time I did not have any problem but I can see it being an

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.2304	1			

Aggregate	Classification	Coverage	Number Of Coding Refer	Reference Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0020	1			
				1	LJB	15/02/2018 13:15

Nodes\\Fit for purpose\41

Document

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0011	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION Alex keable

No		0.0011	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION jb

No		0.0020	1			

				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Nodes\\Fit for purpose\42

Document

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0020	1			
				1	LJB	15/02/2018 13:15

Nodes\\Fit for purpose\43

Document

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0020	1			
				1	LJB	15/02/2018 13:15

Nodes\\Fit for purpose\44

Document

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0020	1			
				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Nodes\\Fit for purpose\45

Document

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0020	1			
				1	LJB	15/02/2018 13:15

Nodes\\Fit for purpose\5

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No		0.0021	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No		0.0013	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0019	1			
				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No		0.0199	1			
				1	LJB	15/02/2018 13:15

Number rank (0- 100) 0=poor 100=excellent.

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0021	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0024	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0011	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0011	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0007	1			
				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0020	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0019	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0012	1			
				1	LJB	15/02/2018 13:15

Aggre- gate	Classification	Coverage	Number Of Coding Refer	Refer- ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0013	1			
				1	LJB	15/02/2018 13:15

Nodes\\Fit for purpose\6

Document

Internals\\Shape Assembly

No		0.0107	1			
				1	LJB	15/02/2018 13:15

Question

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No		0.0067	1			
				1	LJB	15/02/2018 13:15

Question

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0098	1			

				1	LJB	15/02/2018 13:15

Question

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No		0.0194	1			
				1	LJB	15/02/2018 13:15

Did you perform well using the haptic APP?

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0105	1			
				1	LJB	15/02/2018 13:15

Question

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0124	1			
				1	LJB	15/02/2018 13:15

Question

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0059	1			
				1	LJB	15/02/2018 13:15

Question

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0059	1			

				1	LJB	15/02/2018 13:15
Question						

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0070	1			
				1	LJB	15/02/2018 13:15
Question|User test						

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0093	1			
				1	LJB	15/02/2018 13:15
Question						

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0103	1			
				1	LJB	15/02/2018 13:15
Question						

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0097	1			
				1	LJB	15/02/2018 13:15
Question						

Internals\\Shape Assembly\\USER TEST EVALUATION.

No 0.0093 1

1 LJB 15/02/2018 13:15

Question

Internals\\Shape Assembly\\USER TEST EVALUATION

No 0.0090 1

1 LJB 15/02/2018 13:15

Question

Internals\\Shape Assembly\\USER TEST EVALUATION-

No 0.0063 1

1 LJB 15/02/2018 13:15

Question

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No 0.0069 1

1 LJB 15/02/2018 13:15

Question

Nodes\\Fit for purpose\7

Document

Internals\\Shape Assembly

No 0.0118 1

1 LJB 15/02/2018 13:15

User test

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No		0.0074	1			
				1	LJB	15/02/2018 13:15

User test

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0108	1			
				1	LJB	15/02/2018 13:15

User test

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No		0.0163	1			
				1	LJB	15/02/2018 13:15

1-100 (0=poor – 100 excellent) NS1

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0115	1			
				1	LJB	15/02/2018 13:15

User test

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0136	1			
				1	LJB	15/02/2018 13:15

User test

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0065	1			
				1	LJB	15/02/2018 13:15

User test

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0065	1			
				1	LJB	15/02/2018 13:15

User test

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0028	1			
				1	LJB	15/02/2018 13:15

code |

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0102	1			
				1	LJB	15/02/2018 13:15

User test

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0113	1			
				1	LJB	15/02/2018 13:15

User test

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0107	1			
				1	LJB	15/02/2018 13:15

User test

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0102	1			
				1	LJB	15/02/2018 13:15

User test

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0099	1			
				1	LJB	15/02/2018 13:15

User test

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0069	1			
				1	LJB	15/02/2018 13:15

User test

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0076	1			
				1	LJB	15/02/2018 13:15

User test

Nodes\\Fit for purpose\8

Document

Internals\\Shape Assembly\\

No	0.0075	1			
			1	LJB	15/02/2018 13:15

code

Internals\\Shape Assembly\\Haptic TEST EVALUATION

No	0.0047	1			
			1	LJB	15/02/2018 13:15

code

Internals\\Shape Assembly\\USER TEST EVALUATION

No	0.0068	1			
			1	LJB	15/02/2018 13:15

code

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No	0.0039	1			
			1	LJB	15/02/2018 13:15

Number

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0073	1			
				1	LJB	15/02/2018 13:15

code

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0086	1			
				1	LJB	15/02/2018 13:15

code

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0041	1			
				1	LJB	15/02/2018 13:15

code

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0041	1			
				1	LJB	15/02/2018 13:15

code

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0163	1			
				1	LJB	15/02/2018 13:15

tNumber rank (0- 100) 0=poor 100=excellent.

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0065	1			
				1	LJB	15/02/2018 13:15

code

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0072	1			
				1	LJB	15/02/2018 13:15

code

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0068	1			
				1	LJB	15/02/2018 13:15

code

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0065	1			
				1	LJB	15/02/2018 13:15

code

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0063	1			
				1	LJB	15/02/2018 13:15

code

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.0044	1			
				1	LJB	15/02/2018 13:15

code

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0048	1			
				1	LJB	15/02/2018 13:15

code

Nodes\\Fit for purpose\9

Document

Internals\\Shape Assembly\\Eleanor NS 1 26-10-2017

No		0.0021	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No		0.0013	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0019	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No		0.0022	1			
				1	LJB	15/02/2018 13:15

75%

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0021	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION (4)

No		0.0024	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0131	1			

				1	LJB	15/02/2018 13:15

Alex Keable – Crouch

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0131	1			
				1	LJB	15/02/2018 13:15

Alex Keable – Crouch

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0155	1			
				1	LJB	15/02/2018 13:15

Did you perform well using the haptic APP?

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Aggre- gate	Classification	Coverage	Number Of Coding Refer	Refer- ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0020	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0019	1			

				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0018	1			
				1	LJB	15/02/2018 13:15

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0012	1			
				1	LJB	15/02/2018 13:15

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0013	1			
				1	LJB	15/02/2018 13:15

Nodes\\Understanding

Document

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0906	1			

				1	LJB	13/01/2018 10:08

I wanted to tweak the interface but its amazng to think I completed the task in a short time

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0435	1			
				1	LJB	13/01/2018 09:52

As I only used this for a short period of time I did not have any problem

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1034	2			
				1	LJB	13/01/2018 09:53

While the task was simple it was interesting to think what more challenging t asks might be accomplished with the robot

				2	LJB	13/01/2018 09:54

The presence of the interface opens up exciting potential allowing VI students to participate more in design exercises in a variety of modules tand beyond into employment?

Aggregate	Classification	Coverage	Number Of Coding Refer	Reference Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1283	1			
				1	LJB	13/01/2018 10:00

I would suggest everyone works with this app It was easy to use, easy to understand. It only took me a few minutes to use it

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1291	3			
				1	LJB	13/01/2018 09:58

I worked great with this device and the interface. My understanding and aims were clear to me

				2	LJB	13/01/2018 09:58

ALL easy

				3	LJB	13/01/2018 09:58

want to try it all again soon

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.0252	1			
				1	LJB	13/01/2018 10:01

had no stress what so ever

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0389	1			
				1	LJB	13/01/2018 10:02

I found the interface very easy to navigate

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Nodes\\Useable

Document

Internals\\Shape Assembly

No	0.0604	1

1 LJB 13/01/2018 09:45

useful, could have had auditory feedback for fixed block

Internals\\Shape Assembly\\Haptic TEST EVALUATION.

No	0.3172	4

1 LJB 13/01/2018 09:47

Notes – I felt as if I managed to use the device and APP well

2 LJB 13/01/2018 09:47

In its current form it serves well as a testing tool, but its usefulness will only be established when being used for more than testing

3 LJB 13/01/2018 09:48

Yes the device was easy to hold and intuitive to use. I was impressed by the feel of the boundaries in the APP when converted to resistance in the device. Being able to feel the weight of the object was also a pleasant sur-

4 LJB 13/01/2018 09:48

The device and APP were both easy to use.

Internals\\Shape Assembly\\USER TEST EVALUATION

No	0.1655	1

1 LJB 13/01/2018 10:08

It was all very interesting. I performed well even though when under pressure my sisght reduces. I felt as if there was no pressure to use the interface and I liked it

Internals\\Shape Assembly\\USER TEST EVALUATION (2)

No	0.0376	1

1 LJB 13/01/2018 09:49

felt that I was able to perform the task set with the apparatus without major issues

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION (3)

No		0.0316	1			
				1	LJB	13/01/2018 10:12

I found it useful, thanks Lisa

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0435	1			
				1	LJB	13/01/2018 09:53

Yes given the time I had however I felt it would be better with more time

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0187	1			
				1	LJB	13/01/2018 09:55

Found I had few problems holding and using the device

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1097	1			
				1	LJB	13/01/2018 10:00

The interface was very clever, I really enjoyed myself and the noises and movement was interwssting
Notes

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.1702	1			
				1	LJB	13/01/2018 09:58

I could see how this device and interface could be useful to all people, not just sighted which is amazing to think about. Someone thinking of us slight imapired is amazing

Internals\\Shape Assembly\\USER TEST EVALUATION.

No		0.1047	1			
				1	LJB	13/01/2018 10:01

soon got the hang of it, and was able to complete the task. At first I tried to push the Avatar through a block

Aggre-gate	Classification	Coverage	Number Of Coding Refer	Refer-ence Number	Coded By Initials	Modified On

Internals\\Shape Assembly\\USER TEST EVALUATION

No		0.0924	1			
				1	LJB	13/01/2018 10:02

I enjoyed using the haptic app and I feel as though I could have performed better with more practice.

Internals\\Shape Assembly\\USER TEST EVALUATION-

No		0.1092	2			
				1	LJB	13/01/2018 10:03

I believe I performed well,as I could construct the shape required within 2 minutes without prior knowledge or extensive practice with the device.

				2	LJB	13/01/2018 10:03

Very easy to use, and hold