Exploring the Micro, Meso and Macro
Proceedings of the European Distance and E-Learning Network 2018 Annual Conference
Genova, 17-20 June, 2018
ISBN 978-615-5511-23-3
ISSN: 2707-2819
doi: https://doi.org/10.38069/edenconf-2018-ac-0057

HAPTIC PROTOTYPE ASSEMBLY TOOL FOR NON-SIGHTED, VISUALLY IMPAIRED AND FULLY SIGHTED DESIGN STUDENTS, STUDYING AT A DISTANCE

Lisa Bowers, Ryan Hayle, Nick Braithwaite, The Open University, Farshid Amirabdollahian, University Hertfordshire, United Kingdom

Abstract

Designers are known to use a blend of manual and virtual processes to produce design prototype solutions. However, often virtual processes can limit the designers' feeling of being "hands-on" with materials and processes. The rise of virtual haptic tools has afforded great potential for designers to feel more "hands-on" with the virtual modelling processes. This paper presents an investigation of an inclusive educational haptic tool and interface. The Geomagic Touch™ device is the selected haptic technology used within the investigation. It is a sophisticated haptic technology which allows users the chance to interact with 3D design via a single point of contact. The haptic rendered interface was designed to facilitate a prototype design process for non-sighted – visually impaired and fully sighted distance learners from The Open University. The parameters examined were (a) *Duration* – measured against an industry standard time taken to assemble a four block prototype, and (b) *Collision rate* – caused by participant between colliding with 3D geometric block during assembly. The results showed that the duration data was within the accepted industry standard, of 5 minutes, and there was little significant difference between duration and collision rate between-groups, indicating that the haptic and designed interface had offered an open accessible tool to both NS-VI as well as FS design students.

Introduction

The haptic prototype assembly project was funded by the eSTEeM project award board at the Open University, Milton Keynes. The eSTEeM awards focus on funding research which will develop STEM teaching and learning for distance learning programmes. The study was inspired by the researchers' previous study work (Bowers et al., 2013) which examined non-sighted (NS) artisans lack of access to Graphical User Interface (GUI). The essence of the lack GUI access is linked to the emphasis on the *graphical* nature of the interface, which limits NS users to singular sense (audio) interactions. The previous work showed that machine haptics can assist NS artisans to locate and interact with 3D objects on-screen and within a shorter duration (m = 16.5 secs) than the sighted control group (m = 18.9 secs). This study examined the use of a novel multimodal haptic interface working with new groups namely distance design students studying at the Open University.

The study requested that all participants (CFS, NS, and VI) worked through *all* conditions, e.g., manual and machine haptic shape assembly tests. This paper initially presents literature which gives a background to human and machine haptics but moreover it evidences that haptic technology is able to assist non-sighted and visually impaired students to gain greater access to applied learning (Wall & Brewster, 2006) through the virtual realm. It then goes on to examine the specific kinaesthetic haptic technology, and reflects on the limitations of GUI to interact with computer aided design (CAD) processes. This project seeks to test whether haptic technology could afford NS, VI students, need to use CAD as part of their learning modules. A dual sensory interface was designed to assist all NS, VI participants to overcome visual barriers through touch, and to spread their learning interactions across multiple senses channels.

Haptics

Touch is one of the earliest sensory developments in the human body, as a foetus in the womb we are able to touch and feel and once a child is born touch is an important sense to connect the child with their parents; it is believed to be an important part of human development and for human interactions (Stanford Encyclopedia of Philosophy, 2015; Minogue & Jones, 2006). The sense of touch, confirms the properties of the objects and the surrounding environment. Although many laypeople may ascribe to a singular form of touch, defined as human skin, digits and/or palm, being in contact with an object. In fact, there are two main subcategories of touch (a) cutaneous touch – feedback with skin and (b) kinaesthetic touch – the location and movement of limbs in space. Seminal works in touch perceptions by Klatzky and Lederman (2003) argues that there is an importance to learning more about the patterns of touch and how we explore and manipulate objects. They assert that many daily exploratory perceptions (EPs) are perceived with little conscious thought, such as, fastening a button without looking first. Often when our sight is unavailable to sighted individuals, through environmental conditions, it is still possible to locate objects through touch, for example, switching on a light in the dark. Klatzky and Lederman (2003) also highlighted how we identify common objects, through contour following. This is defined as a common EP defined as tracing the exterior and interior surfaces and edges of objects using one/several digits of one hand. Contour tracing is typically defined as a kinaesthetic EP and can establish shape, form and textural surface of an object, in a relatively short period of time. The Geomagic Touch device, used in this study, employs contour following as the main interaction technique, and using the devices single point tip (end effector) on the stylus, users can pick up and put down objects or push objects back and forth around the environment at will.

Haptics and education

Minogue and Jones (2006) assert that the critical role of touch permeates educational language. They describe how we discuss *grasping knowledge* or *getting a handle on learning*. Within the discipline of design educators assert the benefits of students gaining fuller access to hands-on learning as a crucial part of design development. Hands on learning is often difficult to facilitate within distance learning due to the nature of the complexities and access to specific real world spaces. The early phase (germinal phase) of the design cycle is typically where hands-on development and concept realisation is more fluid. As a consequence, this paper examines the use of haptic technology at the early phase of design to aid students design thinking and firm up shape and form concepts effectively in a short period.

Haptic technology is a relatively contemporary growth area within the area of Technology Enhanced Learning (TEL). More recently educational institutes are recognising the benefits of haptic technology and its ability to interact with virtual data in a more innate and meaningful way. Over the last five years there has been a growth of haptic technology; and disciplines such as design and engineering are exploring the field of haptics along with the creative and cultural industries where haptics is used as a tool to touch the 'untouchable'. Often in museums and art galleries visitors are requested not to touch valuable exhibit pieces, this can limit NS visitors who naturally use touch to examine objects. Previous studies by Brewster (2005) have shown haptic technology being used to provide instant tactile feedback from 3D simulations of artefacts, thereby allowing all visitors to engage with "untouchable" objects online or onsite. Further work by Brewster, Wall, Oakley, and McGee, (Wall & Brewster, 2006; Brewster, 2005; Oakley et al., 2000) support the use of kinaesthetic haptics to engage additional sensory needs users with digital practices, this type work was also shown by Colwell and Petrie (Brewster & Brown, 2004; Colwell et al., 1998).

The prototype process

Since the beginning of the Bauhaus School (circa 1919-1933) design students' have been trained to craft, sculpt and model early phase prototypes by hand. However, since the Bauhaus ethos of crafting objects have diminished due to the invention of CAD. CAD has facilitated designers to be highly skilled at 3D digital crafting processes, thereby reducing the need for hands-on skills. Cheshire, Evans, and Dean (2001) state that 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. By combining hands-on skills with digital efficiencies designers will be able to maintain modelling skills but using new sensory interactive platforms to showcase their design talents.

Method and materials

The following outlines the materials and methodologies of the Shape Prototype Assembly Test, set within the Esteem funded project. The test was answer two specific research questions, (a) Can machine haptics (MH) convincingly mimic all users touch interactions to assemble a physical shape? (b) Specifically could NS, VI participants be able to not only understand the touch perceptions but to assemble the shapes to make one finished prototype, within the given standard time of 5 minutes. The assembly test was a focused proof of concept test and as such used a mixed method case study approach to gain a wider assessment of haptics performance. Quantitative results were shown by running between-group data tests using SPSS v10, specifically analysing duration and collision rates and comparing them across all groups and between manual and machine modes. Qualitative data results were assessed using NVivo v21, to enable all participants' evaluations and feedback to be refined and assessed, qualitative data was gathered from (a) Think-Aloud technique, and (b) Pre and posttest Lickert questionnaires.

Kinaesthetic single point haptic device

In order to select the correct form of haptic device the specific attributes for user interaction were analysed, with particular reference given to the user interactions for NS, VI participants. One of the main required attributes of the device was rising scales of force feedback; the device would need to guide the NS, VI users using a varied scale of force (gauged in Newtons) to allow the NS, VI users enough guidance to trace the contours of objects, to establish location and to guide effectively within a standard setting of time. The Geomagic Touch device was justified to be the appropriate device for this study as it was most suited to all of the user attributes, as well as working on similar principles to known tools for CAD such as the graphical stylus and tablet. The Geomagic Touch™ tool is a personal haptic device which is presently desk bound. Using the Geomagic Touch, with a single point stylus, allows users to feel and trace the contours of 3D virtual objects on-screen, whilst the software tracks the exact location of the stylus tip in virtual space. The Geomagic Touch can offer up to 6 degrees of freedom (6DoF) allowing the user greater freedom of movement offering 3x dynamic and 3x passive. The most limiting factors of the Geomagic Touch tool is that it is single stylus and used by the dominant hand. Many NS, VI users track and trace objects using both hands, and use cutaneous and kinaesthetic modes of haptics to gain maximum feedback. As at the time of this paper, there is currently no commercially viable device which could mimic all the aspects of human haptic feedback, then the Geomagic Touch with 6 DoF and the similarities to graphic tools was selected as the most appropriate for these users.

Prototype design

In order to make the focus of the study about usability and haptic performance of a novel interface and less about the aesthetics, form, surface of the prototype, the researcher designed a specific prototype model prior to testing. The model was designed to offer reference to the origins of craft and design – Bauhaus School. Therefore, a *pastiche* of the Walter Gropius chair (circa 1934) was created. The original Gropius chair is shown as image Figure 1, and the pastiche chair is shown in image Figure 2 (Appendix 1). The Gropius chair was selected due to its iconic status, but moreover its simplicity, and brevity of parts to aid rapid assembly. The pastiche chair was 3D scanned and then transcribed to the virtual bounded space, and a 3D model of the prototype was printed using a 3D printer to enable NS, VI participants the chance to establish the form and shape of the prototype they were requested to assemble.

Participants

Twenty participants, (n = 10) non-sighted and visually impaired and (n = 10) sighted design students were invited to join the Shape Prototype Assembly Test via The Open University student research teams, and selected for the test by the researcher working on their experience and abilities within design and prototype methodologies. (Table 1, Appendix 1).

ISBN 978-615-5511-23-3

Manual haptic condition

Participants were requested to assemble 3D geometric blocks in two haptic modes. The first mode assembly was manual and the second was machine. All participants were seated at a table and presented with four 25 x 4 x 23mm (palm sized) foam shapes (1x arch 3x cuboids). A single foundation block was magnetically fixed to the table, and three further blocks were placed by the participant's dominant hand. Participants were requested to initially select one cuboid, from the box, and to push it until it connected with the foundation block this was repeated until only the arch shape was left. The final arch shape was then picked up and placed in top of the foundation block which completed the assembly. The duration of the manual shape assembly test was recorded using a digital stopwatch and completion was the final block being placed and the participant removing their hand from the model. Both manual and machine mode tests were recorded using a handheld camera.

Machine haptic conditions

As with manual test participants were seated at a desk, however, in machine haptic mode participants were presented with a single 21" display screen. The screen was specifically aligned with the Geomagic Touch haptic device. On the startup screen, a bounded virtual environment was presented. NS-VI participants were initially allowed to track and trace the bounded space prior to the official test starting up, to allow to mentally map the space and the 3D blocks. On startup the screen featured two blocks 25 x 4 x 23mm (simulated foam shapes). A yellow cuboid was the foundation block fixed to the floor of the environment and a red cuboid was setup in line with the foundation block. Participants were requested to use push actions to connect shapes, and each time they needed a shape to summon it via pressing down the space bar on the keyboard. This process was repeated until the final arch block, which was simply picked up and stacked on top of the foundation block. The digital stopwatch embedded in the virtual interface would time up to the allotted 5 minutes and designed to shut down all activity at 5 mins.

All participants were requested to complete a short training test prior to the main test. As previously discussed NS, VI group participants were permitted to touch and explore all manual blocks, the 3D prototype chair, the virtual bounded space and the Geomagic Touch™ device prior to commencing the test. This was permitted to allow for the lack of sight and to offer the NS, VI participants a full mental picture of the materials and technology used.

As previously discussed, all participants were requested to complete a pre-trial training task to familiarise themselves with the "feel" of the haptic force and guidance. The pre-trail test was a simple "pick up and put down" task Figure 5 (Appendix 1). *CFS* Participants were requested to "pick up" the cube and "put down" the cube according to the floor markers, NS, VI participants were asked to use audio and haptic guidance force to pick up and put down the block.

ISBN 978-615-5511-23-3

Dynamic haptic actions

In order to co-ordinate a consistent action, used throughout testing, all participants were asked to use one action to connect shape blocks, namely the push action (see Figure 6. and 7., Appendix 2).

Figure 6. and 7., (Appendix 1) visualise the "push action" using a blue arrow to emphasise the direction of force, in both manual and machine modes. The push action was selected over the pre-trial pick up and put down action due to the simplicity and brevity of this action, moreover the action was considered more user-friendly to NS, VI participants was it used the environment to guide the action, which is akin to real-world interactions for non-sighted individuals. All participants confirmed that the action was easy to understand completed it successfully throughout the assembly tasks.

Results and analysis

Qualitative

The qualitative results were obtained via the data gathered from using the Think-Aloud technique throughout the test. All participants contributed qualitative data. The raw data was prepared initially by transcribing the Think-aloud then creating a coding scheme within NVivo v 21, and then reacting to correlate emerging themes. First level data analysis showed that the most commonly repeated word used was "easy", and the second two were "understandable" and "interesting". Further analysis on the themes revealed some sub theme headers, these were set around cross referenced nodes relating to user's feedback on tool use usability, understanding, and fit for purpose.

Agreements (moderate and extreme)

There was a consensus of moderate and extreme agreement between NS-VI participants was set around the initial perceptions of the haptic device and the actual perceptions from using the tool, 50% of NS, VI participants noted that the interface and device was easy to control which was contrary to their pre-trial statements, which revealed that they believed the interface would require higher level mathematical or programming skills to use and control the tool. There was also a moderate agreement by NS-VI participants that they could perceive the mass of the geometric shapes on screen and that they could understand the assembly techniques as it was described to them. Participant NS9 stated

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

He went on to say:

> *"Moving from a mental picture to creating a prototype was satisfying. Without the interface I can't conceive how the task could be accomplished on my own.*

ISBN 978-615-5511-23-3

> *Only [sic] other alternative would have been a sighted assistant to do all the work".*

There was also a shared extreme agreement across all groups that specifically using the single point kinaesthetic device (Geomagic Touch) made the process simple and intuitive to control. However, one participant NS8, indicated an innate need to use both hands to interact with the virtual 3D objects on-screen, 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".*

The CFS group showed an extreme agreement with how well haptics offered more refined sensitivity of pressure and touch, than 2D graphics tools. They noted specifically that when the probe connected with the virtual walls and objects they could perceive that they were touching the walls and floor and that they knew the shapes were foam rubber and softer in surface than the environment walls. They appeared surprised at the convincing noise feedback of the end-effector as it connected to the bounded wall, participant CFS5 commented, the device was easy to hold and intuitive to use. I was impressed by the feel of the boundaries in the interface when converted to resistance in the device. Being able to feel the weight of the object was also a pleasant surprise.

Overall the consensus was that the haptic interface was useful and usable and allowed for ease of use of the haptic device and assembly task for both groups. However, both groups also stated that they would like to select more function audio feedback functions and alter the pressure of the objects as they felt necessary.

Quantitative

The raw data for duration and collision rates did not have a normal distribution when examining raw data across both groups and both test modes. Therefore, a non-parametric statistical test was used in the form of a Mann-Whitney U test this was used to understand whether there would be any significant difference in the results from between-group, and between haptic mode data. The metrics examined in both between groups analysis were duration (time recorded up to 5 mins) and collision rate (nCollisions – contact with other objects on screen e.g. walls, floor, other shapes).

Table 2, (Appendix 1) shows that by running a Mann-Whitney U test, there was no statistically significant difference between between-groups, as shown by the p values and z value. The box plot, shown above in Figure 8 and 9 (Appendix 2), revealed that the manual mode on between-group test resulted in very little difference in time taken to complete the prototype task, but there was a moderate difference overall between manual and machine. Sample data for machine haptic between-group test, again showed contextually a small difference of time, with the longest duration shown as an outlier for a non-sighted participant.

The *nCollision* was pre-defined as a single block colliding with another block or environment whilst in the process assembling the prototype. The nCollision data was initially transcribed from recordings of every participant in manual and machine modes. The data was then analysed by two inter-raters, the second rater's sample size was calculated at 80% coding sample calculated using Cohens Kappa (k) which resulted in a moderate agreement result (0.50), meaning that between the two inter-raters, there was a moderate agreement of the collisions made. The collision rates showed again little statistical difference between-groups, and between modes.

Discussion

Scali et al. (2013) assert that the use of CAD can stifle designers' creative sensibility and that touch needs to be held as a key interaction within the early phase of the design prototype cycle. Design students in particular need to maintain a key sense of tactile interaction with materials and process to aid learning. This project aims were to find new ways to allow design students the opportunity to maintain the qualities offered via hands-on interaction within the early phase of design. It was important to the researcher that the facilitation of tactile interaction should be utilized to aid non-sighted and visually impaired students greater access to digital design processes. The research question 1 and 2 could be answered positively, RQ1, using qualitative feedback it has been shown that all participants could understand and perceive the environments and the objects within. RQ2, using a mixture of qualitative and quantitative it has been shown that all participants could use the tool to assemble one prototype well within the standard time. The metric data showed moderate differences between manual and machine haptics which highlights there is still work to do to develop the haptic device force and guidance. It could be feasibly hypothesized that the difference between manual and machine haptics could be due to lessened practice as the machine haptic are still novel to the participants and more training could be offered in future testing.

Future

Future work will examine how to enable users a bespoke and more realistic haptic feedback for drawing and developing shape with tactile line. For students with additional needs the element of easily tactile drawing lines could extend to more exploration of meaningful drafting and drawing lines and line adjustment on the fly. Therefore, future work proposes to review a user-led case study of design students registered with the Open University, and aim to analyse how haptic feedback can be conveyed to user and which model of HCI could be used to afford the most innate interactions.

References

1. Bowers, L., Bowler, M., & Amirabdollahian, F. (2013). Haptic cues for vision impaired art makers: "seeing" through touch. *IEEE, 2013*. Manchester.

2. Brewster, S. A. (2005). Impact of haptic 'touching' technology on cultural applications. In J. Hemsley, V. Cappellini, & G. Stanke (Eds.), *Digital Applications for Cultural Heritage Institutions* (Chapter 30, pp. 273-284). Aldershot, England: Ashgate.
3. Brewster, S. A., & Brown, L. (2004). Tactons: structured tactile messages for non-visual information display. *Proceedings of the Australasian User Interface Conference 2004, Dunedin, New Zealand, 18-22 January 2004*, 15-23.
4. Chesire, D. G., Evans, M. A., & Dean, C. J. (2001). Haptic Modelling – An Alternative Industrial Design Methodology? *Proceedings of Eurohaptics, 2001,* 124-128. Birmingham: Eurohaptics.
5. Colwell, C., Petrie, H., Kornbrot, D, Hardwick, A., & Fumer, S. (1998). Haptic Virtual Reality for Blind Computer Users. *Proceedings of the 3rd International ACM Conference on Assistive Technologies (ASSETS'98)*, 92-99. ACM Press. doi: 10.1145/274497.274515
6. Klatzky, R. L., & Lederman, S. (2003). The haptic identification of everyday life objects. In Y. Hatwell, A. Streri, & E. Gentaz (Eds.), *Touching for Knowing: Cognitive psychology of haptic manual perception* (Chapter 7, pp. 105-121). Philidephia: John Benjamins North America
7. Minogue, J., & Jones, M. G. (2006). Haptics in Education: Exploring an Untapped Sensory Modality. *Review of Educational Research, 76*(3), 317-348.
8. Oakley. I, McGee, M. R., Brewster, S., & Gray, P. (2000). *Putting the feel in 'look and feel'.* Paper presented at the Conference on Human Factors in Computing Systems, 2000, Hague, Netherlands.
9. Scali, S., Shillito, A., & Wright, M. (2013). *Thinking in space: concept physical models and the call for new digital tools.* Crafts in the 20th Century. Edinburgh.
10. Stanford Encyclopedia of Philosophy (2015). Touch. Retrieved April, 2018, from https://plato.stanford.edu/entries/touch/
11. Wall, S., & Brewster, S. (2006), Feeling What You Hear: Tactile Feedback for Navigation of Audio Graphs. *CHI 2006 Proceedings – Disabilities*. Montréal, Québec, Canada.

Acknowledgments

We are grateful to our colleagues in the Open University, more specifically the Esteem Group, Milton Keynes, UK. Thanks must also go to all of the design group academics, but the greatest thanks must go to all student participants who travelled considerable distances to attend the test trials and gave such frank and open feedback.

Appendix 1

Table 1: Participant Demographics

Participants	No.	Dominant hand (L/R)	Age (Years) Mean ± SD
Males (NS/VI)	5	2/3	42 ±22.8
Females (NS-VI)	5	1/4	47 ±14.9

ISBN 978-615-5511-23-3

Males (FS)	7	0/7	33 ± 13.1
Females (FS)	3	1/2	29.6 ± 5.5
Total	20	20	37.9± 8

Table 2: Mann-Whitney U test results

Test	Z result	P value
Both groups, VP, Duration	-2.27	0.82
Both groups, VP, Collision	-1.43	0.52
NS Duration VP & MP	-1.06	0.28
FS Duration VP & MP	-1.37	0.17

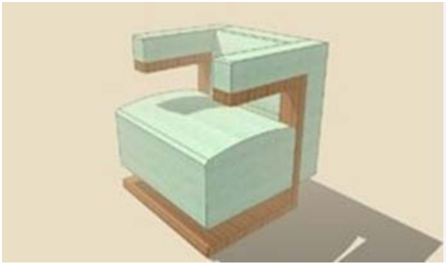
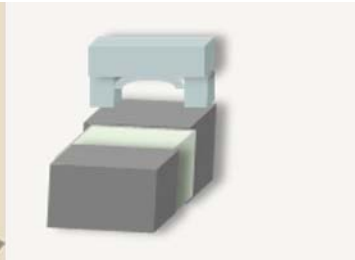



Figure 1. An Example of Walter Gropius block chair
Figure 2. A sketch model of a Bauhaus inspired block chair

Figure 3. Manual prototype blocks

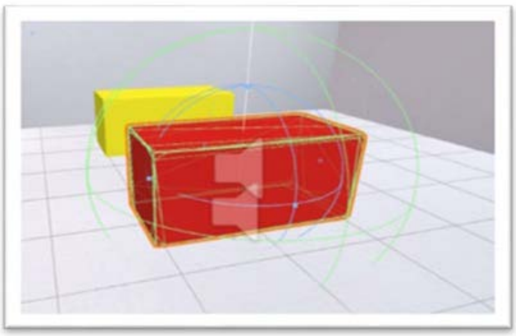
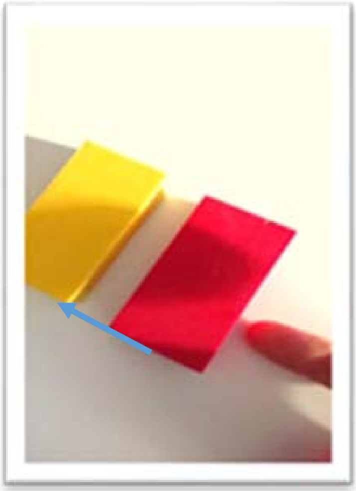


Figure 4. Virtual screen shot of the prototype shapes within the environment

ISBN 978-615-5511-23-3

Figure 5. Preliminary training screen using a "pick up" and "put down" task

Appendix 2



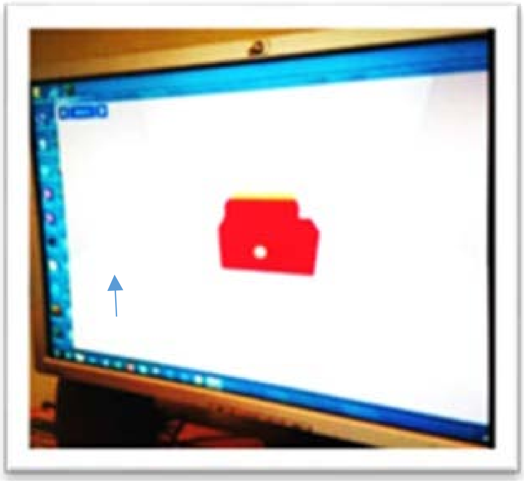


Figure 6. Manual prototype showing the push technique employed in this test
Figure 7. Machine haptic prototype showing push technique employed in this test

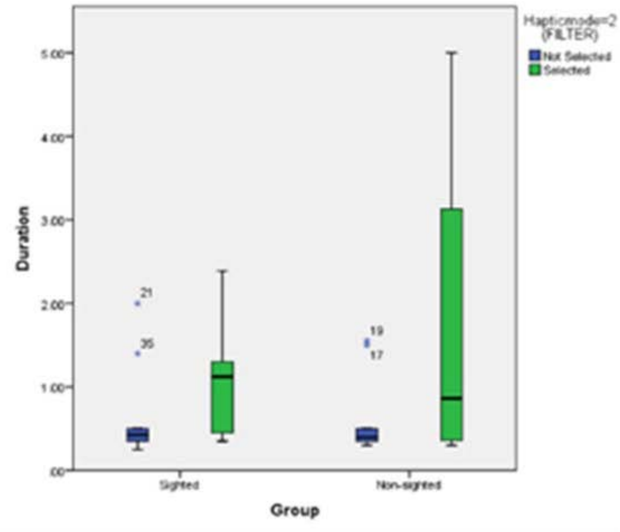
Results Qualitative

Table 3: Coding, Phase 1 Haptic

"It was satisfying accomplishing something which I had thought impossible/very difficult in a relatively easy manner".	Prior perceptions of difficulty Satisfied at completion
"Moving from a mental picture to 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".	Mental imagery Autonomy
"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".	Request for both hands enabled to interact

ISBN 978-615-5511-23-3

Results Quantitative



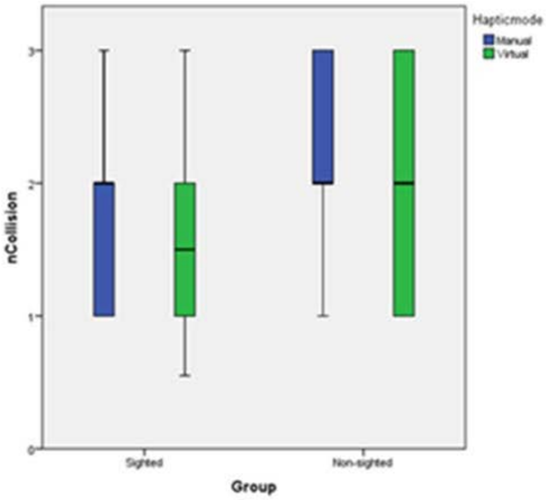


Figure 8. Box plot featuring non-sighted and sighted time to complete task in M and MH modalities
Figure 9. Box plot featuring non-sighted and sighted collisions in M and MH modalities

ISBN 978-615-5511-23-3