The Development of Assistive Technology to Reveal Knowledge of Physical World Concepts in Young People Who Have Profound Motor Impairments

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Abstract

Cognitively able children and young people who have profound motor impairments and complex communication needs (the target group or TG) face many barriers to learning, communication, personal development, physical interaction and play experiences, compared to their typically developing peers. Physical interaction (and play) are known to be important components of child development, but this group currently has few suitable ways in which to participate in these activities. Furthermore, the TG may have knowledge about real world physical concepts despite having limited physical interaction experiences but it can be difficult to reveal this knowledge and conventional assessment techniques are not suitable for this group, largely due to accessibility issues.

This work presents a pilot study involving a robotics-based system intervention which enabled members of the TG to experience simulated physical interaction and was designed to identify and develop the knowledge and abilities of the TG relating to physical concepts involving temporal, spatial or movement elements. The intervention involved the participants using an eye gaze controlled robotic arm with a custom made haptic feedback device to complete a set of tasks. To address issues with assessing the TG, two new digital Assistive Technology (AT) accessible assessments were created for this research, one using static images, the other video clips.

Two participants belonging to the TG took part in the study. The outcomes indicated a high level of capability in performing the tasks, with the participants exhibiting a level of knowledge and ability which was much higher than anticipated. One explanation for this finding could be that they have acquired this knowledge through past experiences and 'observational learning'. The custom haptic device was found to be useful for assessing the participants' sense of 'touch' in a way which is less invasive than conventional 'pin-prick' techniques. The new digital AT accessible assessments seemed especially suitable for one participant, while results were mixed for the other. This suggests that a combination of 'traditional' assessment and a 'practical' intervention assessment approach may help to provide a clearer, more rounded understanding of individuals within the TG.

The work makes contributions to knowledge in the field of disability and Assistive Technology, specifically regarding: AT accessible assessments; haptic device design for the TG; the combination of robotics, haptics and eye gaze for use by the TG to interact with the physical world; a deeper understanding of the TG in general; insights into designing for and working with the TG.

The work and information gathered can help therapists and education staff to identify strengths and gaps in knowledge and skills, to focus learning and therapy activities appropriately, and to change the perceptions of those who work with this group, encouraging them to broaden their expectations of the TG.

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Author's Declaration

Some of the material contained within this thesis has been previously published in the publications referenced in section 1.8.

Definitions

Glossary

Augmentative and Alternative Communication (AAC): “describes various methods of communication that can ‘add-on’ to speech and are used to get around problems with ordinary speech. AAC includes simple systems such as pictures, gestures and pointing, as well as more complex techniques involving powerful computer technology.” (Communication Matters 2015c).

Assistive Technology (AT): “Assistive technology is any product or service that maintains or improves the ability of individuals with disabilities or impairments to communicate, learn and live independent, fulfilling and productive lives.” (Phillips 2012).

Communication books: “Provide pages of symbols, usually organised by topic. Depending on the age, cognitive and physical abilities of the user, the page may have anything from one to many symbols on a page. The topics depend on the age, ability and interest of the Augmentative and Alternative Communication (AAC) speaker.” (Communication Matters 2015a).

Communication Device / Voice Output Communication Aid (VOCA) / Speech Generating Device (SGD): “technologies that enable a person with limited speech or no usable speech to visually display their words or speak through the assistance of electronic communication devices with voice output.” (Scherer 2000).

Environmental Control Systems (ECS): “specialised systems which give people who have limited physical ability more independence to do everyday tasks, such as opening the door and switching the lights on.” (Toby Churchill Ltd 2011).

Executive Functions: “Specific mental functions especially dependent on the frontal lobes of the brain, including complex goal-directed behaviours such as decision-making, abstract thinking, planning and carrying out plans, mental flexibility, and deciding which behaviours are appropriate under what circumstances; often called executive functions” (World Health Organization 2007).

Eye gaze: Using eye movements to select cells on a screen-based user interface.

E-Tran frame: “An E-Tran frame is a sheet of stiff, transparent plastic (Perspex) onto which symbols or words can be stuck with Blu-Tack or Velcro. The communication partner faces the user and holds the chart up between them. The user gazes at the letter, symbol, or word they want to say. Initially one symbol or word will be placed at each corner. As the user and communication partner become more skilled, symbols can be added in the middle of each side. The method can be developed using colour or number coding systems so that more items can be accessed.” (Communication Matters 2015b).

Haptic: “Relating to the sense of touch, in particular relating to the perception and manipulation of objects using the senses of touch and proprioception: haptic feedback devices create the illusion of substance and force within the virtual world” (Oxford English dictionary 2016a).

Sensorimotor: “Physiology - (Of nerves or their actions) having or involving both sensory and motor functions or pathways.” (Oxford English dictionary 2016b).

Somatosensory: ‘”Physiology - Relating to or denoting a sensation (such as pressure, pain, or warmth) which can occur anywhere in the body, in contrast to one localized at a sense organ (such as sight, balance, or taste). Also called somaesthetic.” (Oxford English dictionary 2016c).

Acronyms / Abbreviations

AAC	Alternative and Augmentative Communication
AT	Assistive Technology
CNS	Central Nervous System
CP	Cerebral Palsy
CYP	Children and Young People
GUI	Graphical User Interface
HAAT	Human, Activity, Assistive Technology
HRI	Human-Robot Interface
ICF-CY	International classification of functioning, disability and health: children and youth version
IR	Infrared
LSA	Learning Support Assistant
NA	Not Applicable
OT	Occupational Therapist
POR	Point of Regard
PP	Pupil Participant
SaLT	Speech and Language Therapist
SaLTa	Speech and Language Therapy assistant
SP	Staff Participant
TD	Typically Developing
TG	Target Group
UI	User Interface
VEC	Victoria Education Centre
VOCA	Voice Output Communication Aid

Chapter 1 Introduction

1.1 Context

Human beings are heavily dependent upon physical movement and communication in order to participate fully in society. During pregnancy, mothers report feeling the movements of their unborn child in the womb, and from birth onwards infants spend much of their time exploring and communicating about their environment.

However, a range of factors, including genetic disorders, disease and injury, can affect the ability to move and to communicate, and can have a profound effect upon a person's life.

These limitations impact on the child's development from a young age and can prevent children and young people (CYP) from having the same real-world experiences as their typically developing peers. *Profound* motor impairment exacerbates this situation and greatly limits communication and opportunities to interact with the physical world. It can also result in passivity and a reduced inclination to initiate (Cook et al. 2000). This in turn may restrict a person's ability to learn about temporal, spatial and movement concepts and, more fundamentally, to engage in physical play. Play itself is regarded as an important component of early child development (Missiuna and Pollock 1991; Besio et al. 2015) but for those who have disabilities, independently initiated physical play can be difficult, or impossible, due to mobility and dexterity impairments. This situation is exacerbated, as most play materials are not designed with this group's needs in mind (Van Den Heuvel et al. 2015).

Technological aids exist which can help to compensate for impairments. This branch of technology is referred to as Assistive Technology or AT. There are an array of AT aids available including powered mobility, walking aids, and communication aids.

Those who have profound motor and communication impairments may have access to AT for communication and control of their environment, but they may be heavily reliant on human assistants to facilitate physical interaction. Even then, these experiences may be relatively restricted. Tactile experiences are frequently facilitated by care-givers or peers using 'hand-over-hand' techniques (Deluca et al. 2006) and, often physical activities are performed in front of a person while they merely look on (World Health Organization 2007).

Furthermore, it can be difficult to ascertain such young people's knowledge and understanding of the physical world, as issues of accessibility make current assessment techniques unsuitable for this group. This project is designed to provide young people with opportunities to explore the physical world and to investigate their understanding of it.

This pilot study is set within the context of Assistive Technology (AT) and motor impairment and is specifically focussed on cognitively able CYP who have profound motor impairments and Complex Communication Needs. From this point on this group will be referred to as the Target

Group or TG.

A robotics-based system intervention was developed which enabled the TG to experience simulated physical interaction. This intervention involved the participants using an eye gaze controlled robotic arm with haptic feedback to complete a set of tasks. A custom made haptic device was created specifically for the TG. To address a lack of suitable assessment techniques, two new digital AT accessible assessments were created. One used static images, the other video clips.

Overall, the participants were found to be highly capable of controlling the robotic arm to perform the intervention tasks. They exhibited a level of knowledge and ability which was much higher than anticipated.

Key research contributions include: a new haptic device specifically designed for the TG; two new AT accessible assessments; a robotics-based system which is accessible by the TG; advances in the understanding of the TG's abilities with respect to spatial concepts.

This chapter introduces: the focus and rationale of the work; the formal research questions, aims and objectives, which resulted from identified gaps in the current literature; an overview of the methodology; a list of the contributions; the context of the EngD; and an overview of the thesis structure.

1.2 Focus

This project is concerned with those CYP whose profound motor impairments limit their movement and, specifically, their ability to physically interact with the world. Such limitations restrict their ability to learn about the physical world in a 'hands-on' manner and limit their ability to play. This research is focussed on improving this situation by providing suitable assessments and a system which enables simulated physical interaction experiences.

The following section provides an overview of the target group. A more detailed description is contained within the Literature review chapter and Appendix A.

1.2.1 Description of the target group (TG)

Cognitively able CYP who have profound motor impairments and complex communication needs (CCN) are the focus of this research. More precise definitions of these characteristics now follow:

Cognitively able: The TG have a good level of cognition (as measured by P Scales: P scale 6 or above in Mathematics, English and Science (Department for Education 2017)). They may have some learning difficulties or 'delays' as a result of their condition.

Profound motor impairments: Their motor impairments place them at the highest levels of the Gross Motor Function Classification System (GMFCS) (Palisano et al. 2007) and the Manual

Ability Classification System (MACS) (Eliasson et al. 2006): Levels IV/V and level 5 respectively. They have control over their eye movements and may have some control over their head and neck.

Complex communication needs (CCN): They have anarthria, which means that they are non-verbal but have some ability to make vocalisations.

1.3 Rationale for the Study

This section examines the rationale and motivation for this study from academic, applied and personal motivation perspectives.

1.3.1 Academic

The TG are a small minority group and appear not to be studied as frequently as some other larger groups. They have complex physical and communication needs, which can mean that they are a particularly difficult group for researchers to study.

Traditional research tools are not easy to use with this group, for example the TG will not be able to complete written questionnaires and interview questions may often be limited to 'yes' or 'no' answers.

It is not easy to assess the TG using current methods (largely due to accessibility issues) and so it is difficult to ascertain what they know, and importantly, what they do not know. They have specific accessibility requirements, usually using eye gaze, and this is not generally catered for by existing assessments. A deeper understanding of these individuals and a flexible approach is, therefore, required for researchers to work effectively with this group. The author was well placed in this regard having worked as an Assistive Technologist with such individuals over the eight years prior to the beginning of this doctorate.

The TG of the present study have little to no functional use of their hands and so have difficulty with unassisted in-hand object manipulation i.e. gripping or holding objects to explore them haptically. This means that they are also unable to grip and manipulate hand-operated systems and peripherals.

There has been little research relating to the use of haptic feedback devices with the TG, and not for the purposes described in this study. Little was known about the ability to identify (touch and) haptic sensations in the hands of the participants prior to the study.

1.3.2 Applied

There are currently limited ways for the TG to experience independent physical interaction and to manipulate physical objects.

Most available (cognitive) assessments are unsuitable for the TG (largely due to accessibility limitations).

1.3.3 *Personal motivation*

The author has worked as an Assistive Technologist with members of the TG for the past 13 years and has observed first-hand the limitations that they face and has attempted to remove some of these barriers by creating opportunities to access toys, environmental control equipment and take part in art activities. This research continues and extends that work.

1.4 Research Questions, Aims and Objectives

In this section, the Research Questions (RQs), Research Aims (RAs) and Research Objectives (ROs) of the study will be discussed. The main or 'overarching' RQ and RA are stated first. These are then divided into four smaller RQs and RAs. Each of the four RQs are further sub-divided, and have Research Objectives (ROs) set against them. The hierarchy for this structure is shown in diagrammatical form in Figure 1.1.

These RQs and RAs are based on the knowledge gaps identified during a state of the art review of the literature (see Literature Review chapter).

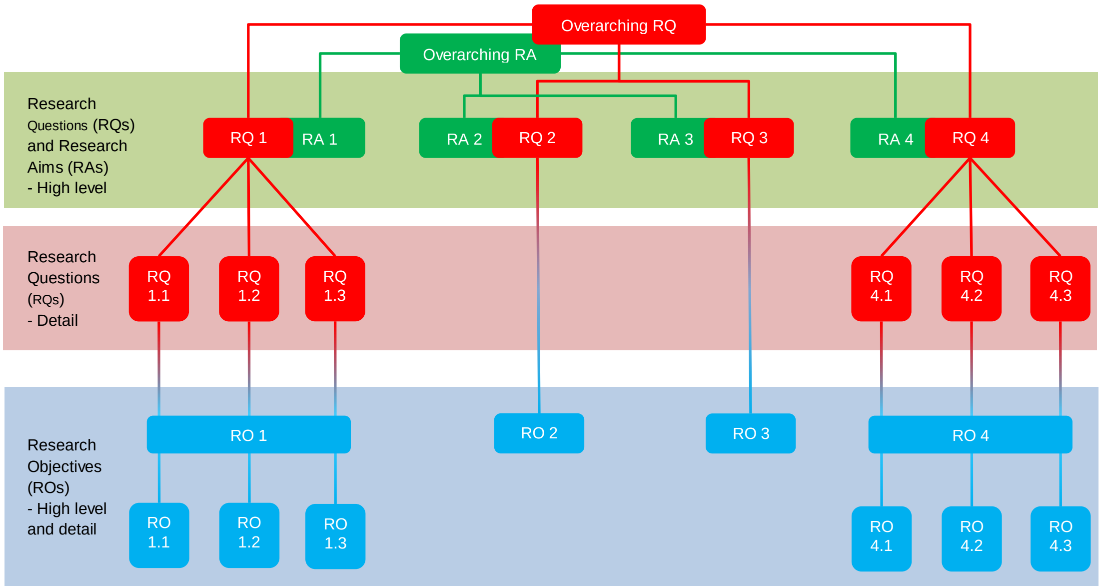


Figure 1.1 Hierarchy of RQs, RAs, and ROs

1.4.1 *Overarching Research Question (RQ)*

The main research question of this study was "How can the TG's knowledge and abilities relating to the physical world be revealed and developed using technology?"

1.4.2 Overarching Research Aim (RA)

Originally, the main overarching aim of this research was to extend the range of ways that this group could independently interact with, and learn about, the physical world, using a new robotic system comprised of AT, robotics and haptics. To evaluate the efficacy of the new robotic system, baseline and outcomes assessments were required. However, existing assessment methods were found to be unsuitable for use with the TG, and therefore the creation of more appropriate assessment methods also became an important component of this research.

This led to a refinement of the overarching RA, which became:

"To use suitable assessment techniques to reveal the TG's knowledge and abilities relating to the physical world and to develop these using a robotics-based system."

The overarching RQ and RA stated above will now be expanded into more detailed RQs, RAs and ROs (see Table 1.1, Table 1.2, Table 1.3 and Table 1.4).

Table 1.1 RQ 1, RA 1, RO 1

RQ (Research Question) 1		
Can the TG accurately identify physical touch and haptic sensations in the palms of their hands and how can this be measured?		
RA (Research Aim) 1		
To measure the TG's ability to accurately identify physical touch and haptic sensations in the palms of their hands.		
RQ 1.1	**RQ 1.2**	**RQ 1.3**
Is the TG able to detect and correctly identify real physical touch sensations in the palms of their hands?	Can suitable haptic feedback devices be created for the TG?	Is the TG able to detect and correctly identify haptic sensations in the palms of their hands?
RO (Research Objective) 1		
To develop and evaluate physical touch and haptic feedback assessments, and suitable haptic feedback devices.		
RO 1.1	**RO 1.2**	**RO 1.3**
To devise and carry out an assessment to identify how accurately the TG can detect physical touch in the palms of their hands.	To develop a range of suitable haptic feedback devices and identify which are the most appropriate for the TG.	To devise and carry out an assessment to identify how accurately the TG can detect haptic sensations in the palms of their hands.
Aims To assess the TG's ability to detect physical touch sensations in the palms of their hands.	**Aims** To create a haptic feedback device suitable for use by the TG.	**Aims** To use the haptic feedback device developed in RO 1.2 to assess the TG's ability to detect haptic sensations in the palms of their hands.
Outputs Knowledge of how accurately the TG can identify physical touch sensations in the palms of their hands.	**Outputs** A suitable haptic feedback device for the TG.	**Outputs** Knowledge of how accurately the TG can identify haptic sensations in the palms of their hands.

Table 1.2 RQ 2, RA 2, RO 2

RQ (Research Question) 2
How can the TG's knowledge of physical world concepts be revealed using technology?
RA (Research Aim) 2
To reveal the TG's knowledge of physical world concepts.
RO (Research Objective) 2
To develop suitable assessments which measure the TG's knowledge of the physical world.
Outputs Assessments which measure the TG's knowledge of the physical world.

Table 1.3 RQ 3, RA 3, RO 3

RQ (Research Question) 3
How could a robotics-based system be used to provide the TG with independent simulated physical interaction experiences?
RA (Research Aim) 3
To create a robotics-based system which provides the TG with independent simulated physical interaction experiences.
RO (Research Objective) 3
The creation of a robotics-based system which provides the TG with independent simulated physical interaction experiences.
Outputs A robotics-based system which provides the TG with independent simulated physical interaction experiences.

Table 1.4 RQ 4, RA 4, RO 4

<table>
<tr><th colspan="3">RQ (Research Question) 4</th></tr>
<tr><td colspan="3">Does the intervention reveal and develop the TG's knowledge and abilities relating to the physical world?</td></tr>
<tr><th colspan="3">RA (Research Aim) 4</th></tr>
<tr><td colspan="3">To reveal and develop the TG's knowledge and abilities relating to the physical world by employing the intervention.</td></tr>
<tr><th>RQ 4.1</th><th>RQ 4.2</th><th>RQ 4.3</th></tr>
<tr><td>Does the TG have pre-existing knowledge and abilities relating to the physical world?</td><td>Does the TG possess the knowledge and abilities required to complete the intervention tasks?</td><td>Did the intervention develop the TG's knowledge and abilities relating to the physical world?</td></tr>
<tr><th colspan="3">RO (Research Objective) 4</th></tr>
<tr><td colspan="3">Use of the physical and cognitive assessments and intervention tasks to identify the TG's knowledge and abilities relating to the physical world.</td></tr>
<tr><th>RO 4.1</th><th>RO 4.2</th><th>RO 4.3</th></tr>
<tr><td>To answer RQ 4.1 using the physical and cognitive assessments described in RQ 1 and 2.</td><td>To answer RQ 4.2 using the intervention.</td><td>To answer RQ 4.3 using the physical and cognitive assessments described in RQ 1 and 2.</td></tr>
<tr><td>Aims
To elicit the TGs' existing knowledge and abilities relating to the physical world through assessment.</td><td>Aims
To reveal and develop the TG's ability to apply their knowledge and abilities relating to the physical world through the intervention.</td><td>Aims
To measure and identify changes between the baseline and outcomes assessments.</td></tr>
<tr><td>Outputs
Baseline assessment results of the TGs' knowledge and abilities relating to the physical world.</td><td>Outputs
Scores and observation notes relating to task completion.</td><td>Outputs
Outcome assessment results of the TG's knowledge and abilities relating to the physical world.</td></tr>
</table>

1.5 The Methodology

The various methodological aspects of the study are discussed in this section.

Methodological choice: Mixed-Methods: This methodology was used, with greater emphasis on the capture of quantitative data compared with qualitative data. This suited the study well as there was a need to capture both numerical, quantifiable data, as well as non-quantifiable data to build a fuller picture of the phenomena under investigation.

Research type: Applied / Practice-based: The emphasis of this study was on solving real-world research issues which are technical in nature. This research was carried out within a special education setting and the focus was on identifying, investigating and addressing issues relating to the pupils. This involved carrying out applied or practice-based research, identifying and focussing on practical problems – i.e. how to assess and build the knowledge and abilities of the TG relating to the physical world.

System design method approach: The original intention was to employ a User Centred Design (UCD) approach i.e. involving the users in the design process. However it was not practical to use a true UCD approach, for two main reasons: 1. Only three pupils attending Victoria Education Centre (VEC) matched the inclusion criteria, only two of whom agreed to participate in the study. These two participants could not have been exposed to both the design process and the intervention as this would have biased the results due to the learning effect. 2. Time and resources were limited. A much longer period would have been required to educate the TG about the design process and to elicit their requirements. The complex nature of the TG, in particular their limited communication abilities would have made it difficult for them to express their thoughts and opinions about such a complex system, given that they have no prior experience of being involved in the design process (Hornof 2009).

For the above reasons, a 'proxy' UCD approach was used i.e. staff from the school's education and therapy departments, who had worked with members of the TG, were involved in informing the design of the assessments and the robotic system. The assessments and prototype were designed *around* the TG's needs and requirements as perceived by 'proxy' users, i.e. people who have a deep understanding of this group.

Principles of Universal Design: These were adhered to during this research. Both the cognitive assessments and robotic system could be accessed in a variety of ways including keyboard, mouse, switch, joystick, touch and eye gaze. The haptic device was designed to fit a wide range of individuals.

Study design: The study was of the 'within-subjects', 'baseline, intervention, outcomes' or 'pre-test, intervention, post-test' variety, with the focus of the intervention stage on task completion. This approach was deemed appropriate as the intention was to identify both pre-existing knowledge, and whether the intervention stage made any measurable difference to this level of knowledge.

1.6 Contributions

This study makes contributions to knowledge in the field of disability and Assistive Technology.

Key Contributions

1. *The development of a robotic augmentative manipulation assistive technology, accessible through eye gaze and providing haptic feedback, that can support participation in academic and play activities, and also reveal the cognitive skills of young people (and children) who have severe motor impairments. This included:*
    - A new means of enabling the TG to have simulated physical experiences, through the combination of a robotics-based system and a haptic device which triggers when the robot arm grips an object;
    - 'Live' and alternating 'camera' / control views of the scene, advancing knowledge of how the TG can interact with such a setup;

- Robot assisted play, with the TG using a robot arm, in a narrative format with multiple narrative paths;
- Insights into the understanding of the TG: they appear to have a greater understanding of temporal, spatial and movement concepts than anticipated; and they are able to control a proxy robotic arm in 3D space, despite having very limited control of their own limbs.

2. *Two approaches to English language AT accessible spoken language comprehension assessment using video and static images:*
   - Specifically relating to the design of assessments which are suited to complex individuals – in particular those who use eye gaze as their primary access method;
   - Employing video clips, rather than static images, may be a more appropriate way of depicting and assessing concepts which involve movement.
3. *A prototype haptic device suitable for the TG (and prototypes which may be suitable for other individuals who have disabilities) used to assess the ability to detect sensations:*
   - Use of the device revealed a better than expected ability of the TG to detect haptic sensations in the palm areas of their hands.

Supplementary Contribution

4. *Contributions 1-3 have developed insights into designing for, and working with, the TG:*
   - An advancement in the consideration of the requirements and needs of the TG and how to supply them with AT equipment, in terms of robotics, haptics, and interfaces;
   - A proxy user centred design was used and evaluated successfully, indicating that this is a viable design methodology for the TG.

1.7 About the EngD and sponsoring organisations

The EngD is a doctoral programme which has an engineering focus. The "research engineer (RE) - pursues a research project while based within a company" (AEngD 2016). This company is referred to as the 'sponsoring company'.

It is important that the sponsoring company and RE's research interests align. Two such organisations are Livability Victoria Education Centre (VEC - a special education organisation) and Smartbox (an Assistive Technology (AT) company). VEC formed both the sponsoring company and the research site for this project. Smartbox kindly supported the project by supplying equipment and software.

The following sections provide descriptions of Livability Victoria Education Centre and Smartbox, and more detail regarding their involvement in this project.

1.7.1 Livability - Victoria Education Centre (VEC)

The former head teacher, Simon Brown, provides a concise description of the school: "Victoria

Education Centre, is a non-maintained, Ofsted-Outstanding special school in Poole, Dorset offering specialised, high quality education, therapy and care for young people aged 3-19. In addition to this we now offer a residential transition service for 18-25 year olds." Brown continues "The students who attend Victoria have physical disabilities or complex medical/neurological conditions and many have additional needs including communication difficulties, learning difficulties and sensory impairments." (Brown 2014).

VEC forms a part of the national charity Livability (Livability 2016), and is based in Poole, Dorset. Eighty-eight pupils attend the school (as of September 2016), and are supported by approximately three hundred staff (Victoria 2014b). The origins of the school date back to 1898, but the school has occupied the present site since 1958 (Victoria 2014a).

VEC is an organisation that aims to push the boundaries of what is possible for those who have disabilities. The school was a partner in the Interreg funded, Times Higher Education (THE) award winning 'SHIVA' research project (McLoughlin et al. 2016).

VEC uses a wide range of technology to assist its pupils including hi-tech eye gaze Voice Output Communication Aids (VOCAs) and Environmental Control Systems (ECS).

In addition to being the sponsoring company, VEC was also the research site i.e. the research was carried out at the school and the resulting prototypes trialled by staff and pupil participants.

Basing this research at VEC had many benefits including:

- Obtaining valuable input and advice from the specialist therapy and education staff at the school;
- The participation of staff and pupils who have helped to shape many stages of the research;
- Working closely with those who used the outputs of the research i.e. the pupil participants, in the intended environment;
- Access to resources including specialist equipment, software and space to carry out the research.

The Industrial Supervisor and gatekeeper for the project was Sarah Gilling, Interim Head of Therapies and School Nursing at VEC. Sarah is a Speech and Language therapist and has many years of clinical and leadership experience, having supervised and mentored many students and staff.

VEC staff members gave advice and provided important perspectives from their different professions. They helped to refine procedures, gave feedback on ideas and prototypes as part of the proxy user centred design approach, and trialled the outputs as staff participants. Their valuable input helped to improve the assessments and intervention prior to being used with the pupil participants.

1.7.2 Smartbox

Smartbox "create assistive technology solutions that help people with disabilities do things that everyone else takes for granted." (Smartbox Assistive Technology Limited 2016). Their hardware and software is used around the world. They are providers of:

- Voice Output Communication Aids (VOCAs): Devices that give a voice to people that cannot speak.
- Environmental Control Systems (ECS): Equipment that enables people to operate technology around the home, such as televisions, hi-fi, lights and more.
- Computer control: A range of technology for people who cannot access a computer with a keyboard and mouse.
- Interactive Learning: Solutions that teach early skills such as 'cause and effect' and 'choice making' as well as alternative access."

(Smartbox Assistive Technology Limited 2016).

Smartbox are based in Malvern in Worcestershire and Bristol. In its present form, the company is approximately 16 years old and employs around 50-55 people. Smartbox generously supported this project by arranging the loan of both equipment and software.

1.8 Publications

The author has authored or co-authored the following conference and journal papers during his doctoral registration period:

Moseley, M., Howat, L., McLoughlin, L., Gilling, S. and Lewis, D., 2019. Accessible digital assessments of temporal, spatial, or movement concepts for profoundly motor impaired and non-verbal individuals: a pilot study. Disability and Rehabilitation: Assistive Technology, 1-11.

McLoughlin, L., Fryazinov, O., Moseley, M., Adzhiev, V., Wu, M. and Pasko, A., 2018. Developing an Accessible 3D Printing Pipeline. Hyperseeing (Special Issue on SMI), (Special Issue on SMI), 57-62.

McLoughlin, L., Fryazinov, O., Moseley, M., Sanchez, M., Adzhiev, V., Comninos, P. and Pasko, A., 2016. Virtual Sculpting and 3D Printing for Young People with Disabilities. IEEE Computer Graphics and Applications, 36 (1), 22-28.

McLoughlin, L., Fryazinov, O., Moseley, M., Sanchez, M., Adzhiev, V., Comninos, P. and Pasko, A., 2014. SHIVA: Virtual sculpting and 3D printing for disabled children, Proceedings of the 22nd International Conference on Computers in Education, ICCE 2014 (pp. 665-670). Nara, Japan: Asia-Pacific Society for Computers in Education.

Moseley, M., 2016a. The use of technology to provide physical interaction experiences for

cognitively able young people who have complex physical disabilities. Technology for Independence Communications 2016, 1.

Moseley, M., 2016b. The use of technology to provide physical interaction experiences for cognitively able young people who have complex physical disabilities. Proceedings of the 30th International BCS Human Computer Interaction Conference: Fusion!, Poole, United Kingdom. 3056366: BCS Learning & Development Ltd. 1-6. Available from: https://www.scienceopen.com/document?vid=72187002-457e-4150-ab6b-ab2c00eb129f [Accessed 03 February 2020].

1.9 Thesis overview

The remaining chapters of this thesis discuss the existing literature relating to the study, the methodology (both theoretical and technical), the assessments and intervention, technical designs, results and discussion, and finally the conclusions.

Chapter 2 – Literature review: A review of the literature was performed to identify what had already been done in the area under investigation and to identify knowledge gaps.

Chapter 3 - Methodology: The methodology used and also the design of the assessments and intervention is discussed.

Chapter 4 – Requirements: The requirements elicitation process is described for both the robotics-based system and haptic prototypes.

Chapter 5 - Technical: The technical aspects of the robotics-based system and haptic device are explained.

Chapter 6 - Assessments: Here the new AT assessment methods which were created for this study are described.

Chapter 7 - Intervention: Here the intervention which involved the Pupil Participants' (PPs') use of the robotics-based system and haptic device is described.

Chapter 8 – Results and Discussion (SPs): The results and discussion of the assessments and intervention when used with the Staff Participants (SPs) are presented.

Chapter 9 – Results and Discussion (PPs): The results and discussion of the assessments and intervention when used with the PPs are presented.

Chapter 10 - Conclusion: Finally, the conclusions drawn from this research study, the strengths and limitations of the study and future directions are discussed.

Chapter 2 Literature Review

2.1 Introduction

The focus of this work is on disability and technology, specifically Assistive Technology or AT. The research involves new AT accessible assessments and a robotics-based system designed for young people who are cognitively able but have profound motor impairments and who are unable to communicate verbally due to Cerebral Palsy (the target group or TG). The assessments and system involve the use of a range of technology including eye gaze, robotics and haptics. This chapter covers literature that is relevant to each of these areas.

2.2 Prevalence of Disability

According to the World Health Organization (WHO) "About 15% of the world's population lives with some form of disability, of whom 2-4% experience significant difficulties in functioning" (World Health Organization 2011) and 8% of children living in the UK are said to have a disability (Department for Work and Pensions 2019). Cerebral Palsy is reported to be the "most common cause of motor deficiency in young children" in Europe" (Cans 2000), occurring in approximately 2 of every 1000 live births (Oskoui et al. 2013).

2.3 Models of disability

Three main models of disability are frequently discussed in the literature: the **medical** model, the **social** model and the **biopsychosocial** model. The **medical** model views disability as a 'problem' which needs to be "fixed", whereas the **social** model proposes that a person's "social structures" (or context) can be limiting and therefore disabling (Cook and Polgar 2014). The **biopsychosocial** model proposed by Engel (1977) and later adopted by the International Classification of Functioning, Disability and Health (ICF) (World Health Organization 2001) (see section 2.4) provides a more holistic model integrating both the medical and social models and incorporates biological, individual and social perspectives of health (World Health Organization 2007).

The current study adopts the biopsychosocial model, taking the stance that the environment and interfaces need to be adapted to suit the individual, who may have reduced physical ability (Whittington 2017). The right interfaces can then remove barriers to allow certain goals to be achieved, to demonstrate knowledge and abilities, and to enable participation in society.

2.4 Description of the TG

To fully appreciate the aims of this study it is important to recognise the impact that the TG's level of disability has upon their lives.

The population under investigation are young people who have profound motor impairments. These impairments place them in the highest categories of the Gross Motor Function Classification System (GMFCS Expanded and revised) (Palisano et al. 2007), which categorises overall motor ability, and the Manual Ability Classification System (MACS) (Eliasson et al. 2006), which relates to hand functioning and the ability to manipulate objects. The severity of their motor impairments means that they have little or no control over almost all of their body and have no speech. They are, therefore, highly dependent upon others and on AT for many aspects of their lives.

For a more detailed description of the TG which describes how their condition affects them compared against the International Classification of Functioning, Disability and Health: Children and Youth version (ICF-CY) (World Health Organization 2007) see Appendix A.

The ICF "is a classification of health and health-related domains. As the functioning and disability of an individual occurs in a context, ICF also includes a list of environmental factors." (World Health Organization 2001).

The ICF-CY (World Health Organization 2007) is "a WHO approved "derived" classification based on the ICF…it includes further detailed information on the application of the ICF when documenting the relevant aspects of functioning and health in children and youth" (World Health Organization 2007).

2.5 Assistive Technology (AT)

The term Assistive Technology encompasses devices, technologies and services. AT can be used to "maintain or improve an individual's functioning and independence to facilitate participation and to enhance overall well-being" (World Health Organization 2019). A vast range of systems and devices can be considered to be AT "including hearing aids, wheelchairs, communication aids and spectacles" (World Health Organization 2019). The Assistive Technology Industry Association (ATIA) state that AT includes "products, equipment, and systems that enhance learning, working, and daily living for persons with disabilities" (Assistive Technology Industry Association (ATIA) 2019). AT can also include mainstream devices, which may or may not have been adapted, and modifications to the environment (Cook and Polgar 2014).

This research study focuses on the following aspects of AT: "functioning and independence to facilitate participation and to enhance overall well-being" (World Health Organization 2019) and "enhance learning" (Assistive Technology Industry Association (ATIA) 2019). The systems produced in this study are designed to enable the participants to partake in activities that they previously could not and to enable them to learn from the experience.

2.6 How the TG can interact with the physical world

Some of the current methods by which this group interact with and learn about the physical world (and develop physical and spatial knowledge and abilities) include: **Manipulation experiences:** these can be facilitated using hand-over-hand techniques (Deluca et al. 2006), whereby another person assists with the handling of objects and materials; **Communication:** basic communication can be achieved using simple methods such as eye-pointing, or more complex communication is possible through use of eye gaze technology; **Control of the physical world** can be achieved using Environmental Control equipment, allowing the control of doors, curtains, audio-visual equipment and some toys; **Musical expression** is possible by capturing small movements using the Soundbeam (Soundbeam 2015), or the Clarion (Open Up Music 2019) using eye gaze; **Mobility** can be provided by others, or for some through powered mobility, depending on the person's level of ability.

2.7 Development, play and disability

Child development is too large a topic to cover in depth here, but certain aspects need consideration.

Children are said to develop through a process of physical interaction with their environment (Piaget 1955). However, according to Vygotsky, children may learn many things by observing others (Cole et al. 1978) or, as Bandura suggests, through others modelling for them (Bandura 1977). Children who have severe motor impairments may have difficulty engaging in physical interaction experiences compared to their typically developing CYP (Musselwhite 1986). The participants in this study were young people, but the inclusion criteria encompassed a broader age range.

Playful experiences, especially physical play, are often dependent on physical interaction and are a key contributing component in aspects of normal child development, including motor, social, language and thinking skills (Sheridan et al. 1999). Children who have physical impairments may have far fewer opportunities to engage in physical play than their typically developing peers (Besio et al. 2015). This can result in secondary disability (Missiuna and Pollock 1991) i.e. secondary cognitive disabilities resulting from reduced physical ability. Thus, it is important that play experiences are provided for this group, and in ways that match their abilities (Cook et al. 2000). Technology can help to provide such experiences, but currently there are limited options, especially for those who have severe motor impairments (Prazak et al. 2004; Van Den Heuvel et al. 2015).

This research study was designed to investigate the participants' current knowledge of physical concepts, which may have been affected by their developmental experiences. It was also designed to provide the participants with new opportunities for interaction that had not been possible previously.

2.8 Assessing the TG

In order to address gaps in a person's knowledge and abilities, the person first needs to be assessed. Conventional assessment techniques can be unsuitable for those who cannot point to nor verbalise answers (Geytenbeek et al. 2010a; Cook et al. 2012). This can make it difficult to assess the knowledge and abilities of the TG and equally difficult for the TG to demonstrate their knowledge and abilities to others.

2.8.1 Cognitive assessments

There are currently few suitable methods for assessing the spoken language comprehension of those who have both anarthria (an inability to produce clear, articulate speech) and profound motor impairments (Geytenbeek et al. 2010a).

It is important to assess CYP who have disabilities in order to develop an understanding of their existing knowledge and any intellectual impairments that they may have (Yin Foo et al. 2013). This understanding can provide a useful baseline, inform the direction and focus of therapy and education (Guerette et al. 1999) and assist with measuring progression. It can also help with identifying a person's suitability for Alternative and Augmentative Communication (AAC) (Geytenbeek et al. 2014). Unsuitable or unsound assessment techniques may lead to inaccurate results and a misrepresentation of an individual's abilities which may lead to unrealistic (Geytenbeek et al. 2010a) or reduced expectations (Encarnação et al. 2014).

At present, Speech and Language Therapists (SaLTs) may use a variety of published and standardised assessment batteries to assess the spoken language comprehension of the TG (Geytenbeek et al. 2010b; Watson and Pennington 2015). Nearly all such assessments are standardised using typically developing children (Yin Foo et al. 2013). This approach may mean that content and methods of completion are not appropriate for the TG given their more limited life experiences and motor impairments.

The TG may be heavily reliant on Assistive Technology (AT) for communication and control but many assessments rigidly require that answers are given verbally, by physical pointing or even through the manipulation of physical objects (Cook et al. 2012).

Some assessment schedules contain a range of permitted adaptations, but these are usually minimal and rarely accommodate the needs of those who are non-verbal and more motorically impaired (Geytenbeek et al. 2010a). For example, more time may be needed to answer. In order to make the assessment materials and administration process suitable for use with the TG, modifications may be required which may then break the standardisation and lead to invalidated results. Indeed, this may lead SaLTs to abandon conventional assessments completely and instead assess informally using observation or assessment schedules that they have developed themselves (Watson and Pennington 2015).

Adaptations to assessments may also alter the nature of what is being assessed, introduce assessor bias and increase cognitive loading (Pennington 2008). Whilst potentially useful as initial screening tools, observation and bespoke assessment approaches lack standardisation and so will have no evidence base to support their efficacy (Watson and Pennington 2015).

When assessing those who provide answers using eye-pointing, there is a risk of confusing 'look to view' or 'look to explore' with 'interactive intention' (Sargent et al. 2013) i.e. confusing general or normal looking with intentional looking. This can result in the assessor misinterpreting responses.

By their physical, often paper-based nature, many standard assessments are restricted to using static 2D images to represent verbs. Symbolic or pictorial representations of certain verb concepts can be difficult to interpret, especially those involving more abstract aspects. The artistic conventions used to represent movement in images e.g. 'curved lines around joints' may not be understood by some (Golinkoff et al. 1987). Verbs such as 'sleeping' do not involve movement and so avoid this problem, but others such as 'releasing' or 'moving forwards' may be better represented using moving images in the form of animations for example, Mayer Johnson's PCS symbol animations (Tobii Dynavox LLC 2018b) or video clips (Golinkoff et al. 1987; Snyder et al. 2012).

Existing (digital) approaches for assessing the TG

The literature reveals a variety of alternative approaches to the assessment of groups who are difficult to assess using conventional methods. The approaches of interest in the current study are those which involve the use of digital technology.

Recently there has been a move by commercial assessment providers to digitise their standard assessments, for example Pearson's Q-Interactive (Pearson Education Ltd. 2018). However, most of these are literal translations of the physical versions and do not provide any additional accessibility options, still requiring that answers be given by pointing, touch or verbal responses, and so they may not be accessible for the TG. Often designed for use with mobile technology such as tablets, their main technical focus is typically on automatic capture and analysis of the results. While the mobile platforms themselves may provide additional accessibility options, the assessment administration procedure may not permit their use.

Researchers have attempted to make standard forced-choice quadrant assessments accessible to a wider range of individuals. Friend and Keplinger (2003) created an assessment based on touchscreen technology and standardised content for use with young infants. Warschausky et al. (2011) converted and adapted the materials of several existing standard assessments to a digital format, importing them into the communication software BoardMaker Speaking Dynamically Pro (Tobii Dynavox LLC 2018a). This provided a range of Assistive Technology accessibility options, including support for switch linear scanning and a head mouse, which were used in the study. Results were obtained from both the standard and adapted versions of the assessments. Adapting the assessments did not appear to affect the results of some assessments significantly when compared to the standard versions. This approach provides a wider range of accessibility options but incurs the additional financial cost of the alternative access software (in this case BoardMaker Speaking Dynamically Pro). Also, the researchers noted that their approach raised legal issues concerning the copyright of the standard assessment materials.

Brain-Computer Interfaces (BCI) have been used as a method of identifying the understanding of spoken language in difficult to assess groups. Byrne et al. (1995) presented participants with images and a matching or non-matching spoken word whilst measuring their brain activity. It appeared that the use of a BCI could be effective at detecting when a participant recognised a match or was conflicted by the image and a non-matching word. This approach identified whether the participant understood the relationship between only one picture and one word. Choosing from multiple choices is more challenging cognitively. Huggins et al. (2015) also used a BCI as a means of eliciting answers to a digitally adapted version of the Peabody Picture Vocabulary Test - 4th Edition (PPVT-IV) (Dunn et al. 2007). They compared the results of the unmodified and BCI-adapted versions of this test and found the results to be "within the expected variation of repeated test administration" but stated that the adapted version took approximately three times longer to complete.

The use of BCIs has the benefits of requiring no motor or verbal responses from the test subjects. However, BCIs may be unsuitable for some including those who cannot tolerate wearing equipment on their heads, or those who have uncontrolled or involuntary movement. There is usually quite a significant attachment and detachment period too, which may test the patience of some. The use of BCI may, therefore, not be feasible in a clinical practice setting.

There are few assessments which are appropriate for use with eye tracking technology. Ahonniska-Assa et al. (2018) used a digitally adapted form of PPVT-IV for assessing the receptive language of individuals who had Rett syndrome (females only). The participants used 'eye-tracking' technology and gave their answers by focussing on one of four forced-choice answer cells. This appeared to be a suitable access method for some, indicating greater proficiency than had been anticipated.

'CARLA' (Computer based Accessible Receptive Language Assessment) (Techcess Communications Ltd. et al. 2018) is a commercially available assessment which works within the communication software MindExpress (Techcess Communications Ltd. 2018). MindExpress supports a range of access methods which are 'inherited' by CARLA. These methods include touch, switch scanning and eye gaze. It is not clear whether this assessment was based on research or clinical experience and the assessment does not appear to have been standardised.

Geytenbeek et al. (2010b) created the Computer-Based Instrument for Low Motor Language Testing (C-BiLLT), a tool for assessing the spoken language comprehension of groups who are difficult to assess, such as those who have severe cerebral palsy. This assessment provides a variety of access methods including eye gaze. The "sequencing of the linguistic complexity of items on the test was based on the Dutch version of the Comprehension Scale of the Reynell

Developmental Language Scales (RDLS)". RDLS is a standardised assessment (Edwards et al. 2011). C-BiLLT is currently undergoing standardisation trials and is being translated into other languages. At the time of the present study, there was no English language version available (the language of the participants in the present study).

Few studies have examined the use of video in the assessment of those who are unable to answer verbally (or motorically). Preferential looking is one approach that has been used to identify a person's receptive language comprehension using video. Golinkoff et al.'s (1987) Intermodal Preferential Looking Paradigm (IPLP) presented two different videos which were played simultaneously and accompanied by an auditory stimulus. Examinees' gaze fixation was observed to identify which of the two videos were fixated upon most by participants and whether this preference matched with the auditory stimulus. The aim of the study was to identify whether the receptive language understanding of young preverbal children exceeded their expressive language, which was found to be the case.

Snyder et al. (2012) used video in a stimulus preference assessment as an alternative to tangible objects or pictures. They considered video to be more suitable than static images for representing social interactions and activities. Assessment flexibility was key to their assessment approach, which enabled a broader range of individuals to be assessed.

Golinkoff et al. (2013) reviewed the applications of their Intermodal Preferential Looking Paradigm (IPLP) during the past 25 years. Their assessment paradigm typically presents only two answer cells. The authors described an inherent limitation with this approach as the 'A not A' problem i.e. the examinee does not know the answer to the question but knows the concept depicted in the incorrect cell, and that this does not match with the answer, and so using a process of elimination is able to deduce the correct answer.

2.8.2 Physical assessments

Existing physical touch assessment methods can be very invasive. Often 'pin-prick' techniques are used to identify a person's ability to detect sensation (New York University School of Medicine 2006; University of Nottingham 2007) and, as with most cognitive assessments, usually require verbal or motor responses from the person being assessed. Such assessments may also be focussed on identifying feeling in specific areas rather a person's ability to sense touch over a larger area such as a hand.

It may not be known whether members of the TG have Sensory Processing Disorder (SPD/SID) (Ayres and Tickle 1980) and so tests that involve sharp or strong sensations may not be appropriate. Equally, light touches may be too weak and localised.

Some assessment packages may be appropriate but are expensive and only a small part of the kit may be relevant, for example, The Sensory Integration and Praxis Test (Ayres 1989; WPS 2016).

2.9 Eye gaze

Studies have examined how a person's vision can be tracked to identify where they are looking and as an input method. The latter point is of particular importance to those who have profound motor impairment.

2.9.1 What is meant by 'eye gaze'?

It is first worth differentiating between the use of the terms 'eye-pointing' and 'eye gaze' (technology) in the context of disability relating to the TG.

Due to their physical impairments and inability to communicate verbally, the TG use 'gaze direction', or 'eye-pointing' as their basic method of signalling "interest and intent" or to "select vocabulary within an Augmentative and Alternative Communication (AAC) system" (Sargent et al. 2013).

This can be achieved using: 'no-tech', 'low-tech' or 'high-tech' eye gaze approaches. A 'no-tech' approach may entail simply looking to the left or right to indicate 'yes' or 'no', whereas a 'low-tech' approach may require the use of a Communication book or E-tran frame. A 'high-tech' approach usually involves Electronic Assistive Technology (EAT) - specifically eye gaze technology for the TG. It is this 'high-tech' technology-based approach which is of interest in this study, and which will be discussed in the sections that follow.

2.9.2 Eye gaze technology

Eye gaze (also often referred to as eye-tracking) technology is often used in conjunction with a computer and a display screen. It can be used in a 'diagnostic' manner to analyse a person's eye-movements and Point Of Regard (POR) (Duchowski 2002).

However, it can also be used 'interactively' (Duchowski 2002) as a means of computer cursor control and selection – in essence, it can replace, or provide a 'hands-free' version of the computer mouse (Ward and MacKay 2002; Sharma and Abrol 2013). This approach affords the user the ability to interact with software-based user interfaces using only their eyes.

There are various hardware and software approaches to monitoring a person's gaze direction. Some are invasive and involve attaching equipment to the user. Others are non-invasive and contactless (Chennamma and Yuan 2013).

A common non-invasive and contactless approach uses infrared emitters to illuminate the pupils of the eye, and a camera to locate the position of the eyes (Chennamma and Yuan 2013). Using this information it is possible to calculate a person's POR on a computer monitor.

This non-invasive form of eye gaze technology is commonly used by the TG and was used within this research study.

2.9.3 Selection approaches

There are various 'interactive' approaches to harnessing a user's gaze. Duchowski (2002) broadly categorises these eye gaze interaction techniques, identifying one method described as 'selective' (like a conventional computer mouse, but using a strategy such as 'dwelling' to 'click') (Hansen et al. 2008). 'Dwelling' or 'dwell-clicking' refers to the process of resting one's gaze on an area of the screen, such as a button, for a specified period of time, for example, one second, after which a system-generated 'click' is issued.

People who have profound physical impairments (such as the TG) and who use eye gaze systems usually adopt this 'interactive', 'selective', 'dwell-clicking' convention (Majaranta et al. 2011).

Nevertheless, other approaches may provide a more natural and flexible interaction method for robotic control, for example: the further the user looks to the right of the screen, the faster the robotic arm would move in that direction (Alapetite et al. 2012).

2.9.4 Eye gaze - an effective input method for the TG?

Access methods other than eye gaze may have been tried with the TG but often found to be unsuitable (Donegan et al. 2009). This may be because their physical limitations render them unable to use conventional input devices such as keyboard and mouse, touch screens, joysticks and trackballs, but also specialist devices such as headpointers and switches.

Eye gaze is a direct access method, i.e. the user does not have to wait to sequentially scan through various options before selecting the one of interest. The eyes are capable of moving at "ballistic" speeds, and so selection speed can be much faster than other indirect methods (Jacob 1990).

Indeed, Dorr et al. (2009), found that gaze-control can outperform the conventional computer mouse (in terms of speed) although this very much depends upon the application. Text and symbol selection methods are often much slower due to measures that need to be taken to avoid the 'Midas touch' (Jacob 1990) i.e. everything looked at causes an action. Nevertheless, combined with an appropriately designed user interface, eye gaze can be an effective input method for those who have no other suitable means of access due to physical limitations, or for those who have degenerative conditions. It can be the "quickest and least tiring option" for such groups (Donegan et al. 2009).

2.9.5 The COGAIN Project

The COGAIN project (Bates et al. 2007) is the largest study concerning the use of eye gaze technology by people who have disabilities to date. The project was instrumental in developing and promoting the use of eye gaze as a means of communication, environmental control and personal mobility for "motor disabled users" (such as the TG) (Bates et al. 2007). COGAIN examined many aspects of eye gaze including the hardware and software, specifically aiming to reduce the costs, widen its use and develop new interaction approaches. The project emphasised "putting the needs of the end user first and foremost" (Bates et al. 2007). This ethos was adopted within the current study. While COGAIN contributed to the foundations of the current project it did not appear to investigate the control of robotics using eye gaze.

2.9.6 Research applications of eye gaze technology

The use of eye gaze technology as an input method leads to a multitude of possibilities for those who have profound motor impairments and can be life-changing. Applications include communication (Bates et al. 2007), control of the user's environment (Bonino et al. 2011), computer control (Sharma and Abrol 2013), and access to the internet and email (Bates et al. 2007).

Eye gaze also provides the potential for learning and play through the use of software games and infrared toys commanded through Environmental Control Systems (ECS) (Donegan et al. 2009), where technology is used to control features of the environment such as operating doors, curtains, lighting, fans, audio-visual equipment and toys.

The TG members who participated in the current study had all used eye gaze technology for a variety of different purposes, including communication, ECS equipment and control of eye gaze enabled software. The current study was designed to further extend the possible applications of eye gaze technology within this context.

2.9.7 Eye gaze and text entry

A substantial body of research has investigated the use of eye gaze technology as an alternative input method to the computer keyboard, for the purposes of efficient text entry (Ward et al. 2000; Hansen et al. 2008; Hoppe et al. 2013). Whilst relevant for those who are literate, this focus is not appropriate for groups such as the TG who typically may have little or no literacy and use symbol based communication instead (Myrden et al. 2014).

2.9.8 The use of eye gaze in three-dimensional (3D) environments

An important aspect of the current study was to use eye gaze control to interact with a 3D environment. Bates et al. (2005) used eye gaze control within virtual 3D environments, combining gaze-control with a 'fly' technique to select distant virtual objects. In their study, users were able to target a desired virtual object onscreen by zooming or 'flying' towards that object. One difficulty with this approach was how to select occluded objects. This was exacerbated if a large object, nearer the camera, obscured a distant smaller object. In such a scenario, the user may not even be aware that the smaller object exists, especially if they do not have an understanding of 'object permanence' (Piaget 1955). The authors noted that this technique can create disorientation and a "loss of context"; it was deemed to place a considerable cognitive load upon the user, requiring that they learn new concepts and keep track of their present location within a virtual context. This may be difficult or even impossible for individuals who have perception or short-term memory impairments (World Health Organization 2007). At the outset of the current study, it was not clear whether the TG had such difficulties.

There exist several commercial software products which involve 3D and spatial concepts, aimed at developing gaze-control skills in CYP who have disabilities. 'Look to Learn' (Smartbox Assistive Technology Limited 2018) provides a series of eye-controlled training activities, some of which involve perspective; 'Eye Can Fly' (Inclusive Technology 2015) provides a cartoon simulation of 3D 'flying', using two dimensional controls which allow the user to look to the left and right of the screen to direct an aircraft towards targets. These activities are useful for engaging early eye gaze users and developing the skills needed for progression towards using communication software. The TG members who participated in the current study had experience of using such software.

2.9.9 Eye gaze, 3D modelling and creativity

The Shiva Project (McLoughlin et al. 2014) created a software system that enables CYP who have disabilities to produce 3D virtual sculptures. The sculptures could then be fabricated using 3D printing techniques so that the creator could show a physical artefact of their work to others. The system included support for eye gaze control, which enabled two of the participants to create models using only their eyes. The software provided the ability to manipulate geometric shapes in three dimensional space using onscreen interface controls. Sculptures were built by adding geometric shapes such as cubes and spheres to a central pole. The shapes could then be moved and operations performed upon them, such as stretch or drill.

The Shiva project demonstrated that young people who have profound motor impairments can develop the skills and knowledge needed to manipulate 3D virtual objects.

The EyeDraw software (Hornof and Cavender 2005) enabled individuals who had severe physical disabilities to produce drawings using point-to-point dwelling to create lines and later shapes and clip-art 'stamps'. The authors noted that people who have disabilities may have little prior experience of art creation and so their drawing skills may initially be less developed. They stated the importance of linking the software to the person's existing communication and access software, providing a route back to the normal usage of the device platform.

2.9.10 Proactive applications of eye gaze

Hyrskykari et al. (2003) examined user interface interventions to assist users when they encounter difficulties in understanding – in this instance, a proactive or anticipatory technique was adopted, whereby foreign language words presented onscreen, were translated when the reader appeared not to understand them. The use of proactive techniques could help to assist the TG by reducing cognitive loading and the demands of a task. For example, when a robotic arm's end-effector nears an object, the software could prompt the user to see if they would like it to be picked up for them.

2.10 Robotics

The innovative work of Papert (1980) with the 'LOGO' programming language and 'Turtle' robots enabled the teaching of mathematical concepts in a manner to which typically developing children could relate i.e. by physically 'doing' mathematics in order to understand it. It was found that children who had difficulty learning mathematics using conventional theory-based approaches could quickly grasp the concepts using the LOGO and Turtle robot method. Children could learn about mathematical shapes, angles and develop basic programming skills by entering a sequence of move and rotate commands into the robot. When these commands were played back, a pen attached to the robot would draw on sheets of paper as the robot moved, creating lines, shapes, or patterns. The children could 'debug' their programs, often by 'being' the robot i.e. walking the path that they were setting for the robot. The concept of learning through 'physical' activities is an important tenet upon which the current study is based and, like Papert's studies, robotics is used.

Forman (1986) also used robots with typically developing (TD) children. The participants of the study completed a series of progressively more difficult tasks using a robot. Forman observed that certain skills emerged as chronological age increased and categorised these into five areas: causality, coordination of multiple variables, reflectivity, binary logic and spatial relations. Cook et al. (2011) later adapted this model for use with children who have disabilities. This will be discussed further below.

Robots have also been used with CYP who have disabilities for similar purposes to those of Papert and Forman. Cook and Polgar (2014) outline the various categories of robotics designed for use by people who have disabilities. The most relevant to this study are 'Assistive robots' which are designed for "Play and Learning". Of particular importance to the current study is how robots can be used as a tool to reveal and develop the knowledge and abilities of individuals.

The assistive robots used with CYP and adults who have disabilities in the studies mentioned below take various forms including arms and remotely controlled vehicles. Some robots operate in three dimensions such as robotic arms, whereas others operate in two, such as wheeled vehicles moving around a table or floor. Some have grippers attached to provide manipulation experiences. Many are physical, but some are virtual representations of real robots.

2.10.1 The importance of assistive robots

In a review of the role that assisted manipulation plays in cognitive development, Cook et al. (2012) suggest that CYP who have profound motor impairments (such as the TG) may have fewer opportunities to interact with the physical environment compared with their typically developing peers. Furthermore, they state the importance of motor experience in cognitive development and of using assisted manipulation, especially robotics, to provide children who have disabilities with opportunities and experiences which can help to reveal and develop their cognitive skills through exploration and discovery.

2.10.2 Applications of assistive robots: cognition, education and play

Assistive robots in the context of play and learning have been used with CYP and adults who have disabilities with a number of different purposes in mind including: **assessment** to reveal **cognitive abilities** including developmental levels and problem-solving skills; to provide **manipulation experiences**; **education** and **learning** experiences including mathematics, sometimes with a focus on **inclusion** and increased **participation**; **story telling**; **play** including block play and feeding animals; and **artistic activities**.

It can be difficult to identify the knowledge and abilities of those who have profound motor impairments using traditional methods. Assessment difficulties have led researchers to explore other methods of evaluating complex individuals, including the use of robots.

Forman (1986) found that robots could be used to reveal the knowledge and abilities of typically developing 3-7 year olds when given problem-solving tasks. Within the population studied, ability and chronological age appeared largely to correlate. Stanger and Cook (1990) identified that able-bodied children as young as one, two and three years old could use a robot and hypothesised that such robots could be used with children who have disabilities. Cook et al. (2005) used a robotic arm with children who have disabilities and reported similar findings to Forman (1986) but Cook's results were based on developmental level rather than chronological age.

Forman's (1986) criteria for identifying robot-related skills were adapted by Cook et al. (2011) for CYP who have disabilities (see Table 2.1). Furthermore, Cook et al. (2012) discussed the cognitive skills required to use such robotic systems and that these can be dependent upon both chronological and developmental age, but also prior experiences and disability level.

Cook's adapted version of Forman's robot-related skills (see Table 2.1) was used to reflect upon the robot-related skills of the participants of the present study.

Table 2.1 Robot skills related to development of cognitive skills (Cook et al. 2010)

Skill		Definition for robot use	Age considerations (typically developing children)	Lego Robot examples
0	No interaction	Child displays no interest in the robot or its actions	NA	NA
1	Causality	Understanding the relationship between a switch and a resulting effect	< 3 action is in switch, tried to use disconnected switches > 4 yrs understood switch made robot move	Use switch to drive robot, knocking over blocks with robot, drawing circles on paper by holding a switch down and turning robot
2	Negation	An action can be negated by its opposite	4 yrs: begin to understand that switch release stops robot	Releasing switch to stop robot
3	Binary logic	Two opposite effects such as on and not on	5–6 yrs: understood 2 switches with opposite effects	2 switches turning robot right/left, or go and stop
4	Coordination of multiple variable Spatial concepts-multiple dimension	Movement in more than one dimension to meet a functional goal	age 5: Could fine tune a movement by reversing to compensate for overshoot, etc	Moving roverbot to a specific location in two dimensions
5	Symbolic play	Make believe with real, miniature or imaginary props	6 yrs: Child ID action in robot not switch, planning of tasks is possible	Interactive play with pretense, i.e. serving at tea party, exchanging toys with friends , pretending to feed animals all using robot
6	Problem solving	Problem solving with a plan – not trial and error, Generation of multiple possible solutions	7 yrs. Designed robot and thought about coordinated effects, planning was possible, Can understand simple programs and debug	Changing strategies to solve a problem such as avoid an obstacle, Changing task to meet the child's own goal, simple programming

2.10.3 Education and play experiences

Some researchers have employed robots to provide children with disabilities with educational and play experiences.

Harwin et al. (1988) developed a system involving a low-cost commercial robot and a vision system for use within special education. The system was switch operated and used for tasks including stacking and breaking apart towers of blocks, sorting, and the 'towers of Hanoi' puzzle. They noted important factors to consider regarding such systems including cost, reliability and safety.

Davies (1995) stated the importance of providing play opportunities for children who have disabilities and developed a playing robot. He impressed upon the reader that such systems should support a range of input devices for different children's access needs.

The POCUS Project (Kwee et al. 1999; Kwee et al. 2002) explored the use of a MANUS manipulator with children and young adults who had cerebral palsy. The participants were able to manipulate real-world objects using the arm. The approach used 'modes' whereby depending on the current mode, the different joints (or degrees of freedom) of the robotic arm could be controlled. The authors reported that the use of these 'modes' sometimes caused confusion and made training longer and more complex. Norman (2013) suggests that modes may be confusing even for experienced users. Modes were therefore avoided in the current study and rather than control individual joints, the user controlled the end-effector (or gripper) position only.

In the ‘PlayBot’ study (Tsotsos et al. 1998) the main goal was to develop a “prototype environment which will assist disabled children in play”. This comprehensive system included a robotic wheelchair with a robotic arm attachment. The child, seated in the wheelchair, would instruct the system via “play sentences” using a tablet computer. Their instructions would then be carried out by the system, for example “find a cube”, “pick it up”. Utilising computer vision techniques, the chair and arm would move the user to the correct position within the real-world scene and pick up the desired object. This allowed the inspection and manipulation of real-world objects in a dynamic situation. The PlayBot system involved a great deal of configuration and adaptation of the environment, which would not be practical in smaller scale projects such as the current study. However, in the current study automated command sequences/macros were used during the introductory/initial stages of prototype use, with the TG. This helped to decrease the number of stages required to perform a task, thereby reducing the cognitive loading. The feature to allow objects to be inspected was partially incorporated within the current study through use of a ‘look’ feature which allowed the scene to be viewed momentarily onscreen.

Cook et al. used a robotic arm with children who had profound physical disabilities for exploration and discovery tasks. Participants used a robotic arm in an interactive play activity to dig up objects from a tub of dry macaroni (Cook et al. 2000; Cook et al. 2005). This involved sequencing, turn-taking and collaboration with the researcher.

In a study of robot-based story-telling, a 12 year old girl with cerebral palsy collaborated with investigators to create a movie of a Greek myth using Lego Mindstorms robots and props (Adams et al. 2008). The participant moved the characters (the robots) and generated segments of the narrative. Through this activity, the participant was able to show her teacher how much potential she had and actively connect with the curriculum and other students.

The IROMEC project (Besio et al. 2008) investigated the use of the ICF-CY (World Health Organization 2007) as a basis for a methodological framework for developing robot-mediated play. The project placed the users’ needs at the heart of the design, which was central to the current study. The abovementioned ICF-CY has been used within this document to describe the disabilities of the TG (see Appendix A).

Several studies have concentrated upon the popular children’s toy LEGO®. The focus has been on enabling children who have disabilities to interact with LEGO, either directly through the use of robots as tools (Prazak et al. 2004; Kronreif et al. 2005), or by using LEGO which has been assembled into controllable robots (LEGO Mindstorms®) (Cook et al. 2011; Adams and Cook 2014; Encarnação et al. 2016).

Prazak et al. (2004) and Kronreif et al. (2005) used robotics to provide an assistance system for children who had physical impairments, to support playing and learning. The resultant system involved a “playground” (LEGO panels) onto which the child could attach LEGO pieces, and build models, using the robot as a conduit.

In another study involving Lego robots, Adams and Cook (2017) enabled children who had motor disabilities to engage in mathematical measurement activities using their AAC devices. Gaps in the participants' procedural knowledge and inadequate conceptual knowledge were identified, but the authors' noted that both improved with practice.

2.10.4 A comparison of physical and virtual assistive robots

A number of research studies have examined the use of robotics in virtual environments (VEs) with groups of participants who are similar to the present TG (Encarnação et al. 2014; Pulay 2015; Encarnação et al. 2016).

2.10.4.1 The benefits of virtual robots

Encarnação et al. (2014) compared the use of virtual and physical ('real-world') robotics with children who had physical impairments. In this study the results favoured the virtual configurations. Pros and cons were identified, as stated below. Pulay (2015) also suggested that using virtual environments could be beneficial. Encarnação et al. (2014) highlighted the relative ease of setup for the virtual robot used in their study but noted that interactive experiences may be weakened. They also noted several points that may be different when using virtual, as opposed to physical robots. These included how others would perceive the participants, as well as the effect upon participation and integration in classroom contexts. These studies demonstrated that young people, such as those of the TG, are able to understand virtual entities and that there may be advantages to their use.

2.10.4.2 The benefits of physical robots

The benefits of using physical robotics have also been noted. Encarnação (2016) commented that It may be much more difficult to create new activities in virtual environments compared to physical. Cook et al. (2005) reported that use of (physical) robots may be "more interesting to the child than two-dimensional computer activities". Prazak et al. (2004), stated that "children should play and learn – at least in the early stages – in real environments, as this is the basis for good performance in the virtual world". In addition, Kwee et al. (1999) found that participants were more motivated by the physical robotic manipulator activities than the virtual. Cooper et al. (1999) also emphasised the importance of physical applications compared to software simulations.

In a more recent study comparing both physical and virtual robotics use with children who have disabilities, Encarnação et al. (2016) found that the results of their study were inconclusive. There were benefits and pitfalls involved in both approaches, physical and virtual, and the authors recommended that further studies be carried out.

2.10.5 Screen-based and real activities

The current study contained both a 'live' scene and a video feed view of the scene i.e. the TG could look directly at the real scene, but also view an onscreen camera feed. Many of the TG's encounters with technology are screen-based and so it was considered important to also provide a non-screen based experience. As noted by Encarnação et al. (2016), physical robots can allow greater interaction between the TG and others. If a member of the TG knocks over a tower of blocks using the robotic arm, there is not only the physicality of blocks crashing to the ground (and watching someone pick them up from the floor), but also the reactions of the investigator or school staff and peers, which could provide opportunities for communication and collaboration.

2.10.6 Robotics and art

Assistive robots have been used to enable children who have disabilities to take part in art activities. The TRIK (Ljunglöf et al. 2009) and LekBot (Ljunglöf et al. 2011) projects both involved systems which instructed a Lego robot to draw shapes using a touchscreen and simulated voice control. The systems were designed for children who had language impairments to learn language through hearing it being used by the system. The current study also used audible utterances to reinforce the actions being carried out, with the intention of this aiding the participants' understanding of the language used.

2.10.7 Access method approaches

Many studies have focussed on the use of switches to control assistive robots. This approach is unsuitable for those who are unable to operate switches, such as the TG. Using a VOCA's infrared capability to control robots (Adams et al. 2008) or a computer and communication aid software (Encarnação et al. 2016) can be a more suitable approach, adding a wider range of access methods including eye gaze, touch and scanning. Importantly, it also adds the capability for the child to both control robots and communicate simultaneously.

2.10.8 Robotic arm orientation

Often, studies have used robotic arms in their standard desk mounted configuration i.e. the 'base' is at the 'shoulder' end and is mounted to a surface such as a table, and the other joints are elevated relative to the shoulder – almost the opposite of the 'natural' or relaxed default position of a human arm. Whilst this is a common robotic arm design and suited to industrial applications, this does not create a direct mapping (Norman 2013) to the user's limb. Care needs to be taken to avoid 'body dysmorphia' when using technology with those who may already have a distorted body image (Pulay 2015). For this reason, the robotic arm used in the present study was adapted and used in a hanging downwards orientation (see Table 2.2 (b)).

Table 2.2 Robotic arm mapping to the human arm

(a)	Standard robotic arm orientation 	Equivalent human arm position 
(b)	Orientation mapping to the human arm 	Equivalent human arm position 

2.10.9 The need for purpose-built assistive robots for CYP and desirable design characteristics

Cook et al. (2010) noted a shortage of assistive robots designed specifically for CYP who have disabilities, stating that the commercially available robots that they examined all lacked accessible Human-Robot Interfaces (HRI's) and so required a third party product or adaptation to the standard interface.

The authors also defined a set of desirable characteristics for assistive robots for CYP who have motor disabilities and later extended these (Cook et al. 2012) offering a range of design considerations when creating new assistive robots for CYP who have disabilities. The authors stated the importance of: a well-designed 'human-technology interface' for use with alternative access methods, one which has a clear layout and uses symbols and/or text to aid understanding; how particular attention needs to be paid to frame of reference issues to prevent confusion; and how the use of AAC devices can enable interfacing of both control and communication. These design characteristics were used to inform the current study and are discussed in the 'Identifying the TG requirements of AT' chapter.

Similarly, Miguel Cruz et al. (2017) conclude that a greater body of evidence is needed regarding the impact upon functional, learning and developmental outcomes relating to robot use with CYP who have CP. The authors call for interdisciplinary teams of developers to use a UCD approach to create low-cost robots for this group.

Lego robots go some way to meeting Cook et al.'s desirable characteristics (Cook et al. 2010). Virtual robots also fulfil many of these characteristics and have advantages over physical robots, but physical robots have advantages over virtual too.

2.10.10 *The benefits of assistive robots*

Many of the studies reported above highlight the important role of assistive robots in enabling CYP who have motor disabilities to:

- demonstrate abilities that they had no other means of expressing – abilities that traditional assessment methods were unable to reveal;
- change the perceptions of others who observed them using the robots;
- play in ways which were accessible for their needs;
- participate in activities that they were previously excluded from;
- gain pleasure from interaction with others.

These studies demonstrate how robotics can be used to help to identify and develop the skills of CYP who have profound motor impairments, and provide a viable means for them to learn about spatial concepts and the physical world, and experience play. Moreover, Cook et al. (2012) emphasise the wider ranging benefits of assistive robots when used by CYP who have disabilities, including language development, participation, inclusion, transferable skills and the carry-over of effects into other domains.

Finally, Cook et al. (2002) stated that CYP similar to the TG have difficulty engaging in activities which generate object-based tactile feedback and Cook et al. (2010) later noted a lack of haptic feedback within the robotic systems they examined. Haptic feedback is the subject of the next part of this literature review.

2.11 Haptic Feedback

One definition of ‘Haptic’ is “Relating to the sense of touch, in particular relating to the perception and manipulation of objects using the senses of touch and proprioception.” (Oxford English dictionary 2016a). Haptic feedback devices use electronic components to create a sense of touch or tactile feedback by artificially generating sensations which are felt within the skin.

2.11.1 How humans sense touch

The human skin contains several types of touch sensors or ‘tactile receptors’. These are usually found in abundance within the smooth or ‘glaborous’ skin of the hands and fingers (Richardson 2008; Linden 2016). Technology-based haptic feedback approaches use a variety of methods to stimulate or ‘innervate’ these tactile receptors to provide a sensation of physical touch. Tachi (2016) states that the Meissner and Pacinian corpuscles (two types of tactile receptors found within the skin) are capable of sensing vibration. Vibration or “vibrotactile” is a commonly used, low-cost approach to simulating touch using electronic components. The current study used this ‘vibrotactile’ method of supplying haptic feedback.

2.11.2 Applications of haptic feedback

Haptic feedback has a variety of applications, many relating to the typically developing, but some are specific to those who have disabilities. Haptic feedback devices that have been used in research relating to people who have disabilities include force-feedback devices; and wearable technology including jackets, gloves, and glasses. Examples are discussed below.

2.11.2.1 Mainstream uses of haptic feedback

Haptic feedback technology has been used in many domains ranging from aerospace to surgery (Stone 2001). Often, haptic feedback is used to provide simulated physical sensations when such sensations are absent, but expected by the user. For example, little tactile feedback is produced when touching a virtual key on a smartphone's onscreen keyboard when compared with a physical keyboard, but haptic feedback can be used as a substitute. A vibration motor within the smartphone spins each time a virtual onscreen key is pressed. This provides the user with confirmation that a keypress has been successfully received (Precision Microdrives Limited 2016). Haptic feedback in the current context refers to the artificial generation of tactile sensations using electronic components.

2.11.2.2 Applications of haptic feedback within the context of disability

Haptic feedback has also been used to assist those who have disabilities, for example, enabling people who have visual impairments to explore virtual environments (Stone 2001).

In their review of the literature concerning the use of haptics and children who have disabilities, Jafari et al. (2016) found only a few studies which had "explored the functionality of haptic systems" for use by children who had disabilities; most of the studies located focused on adults.

Some studies have examined how robotic teleoperation systems with haptic feedback could be used to provide CYP who have disabilities with assisted object manipulation and play experiences. Becerra et al. (2018) compared the ability of a group of TD adults and five year old children to identify the properties of hidden objects using both manual exploration and a robot teleoperation system with haptic feedback. The authors found that the adult participants were accurate using both the manual and technology methods, whereas the children were more accurate in the manual tasks. However, the authors suggested that the technology approach could be suitable for children who have disabilities who may not be able to manipulate objects using their hands.

Sakamaki et al. (2018) investigated using a robot teleoperation system with haptic feedback with and without "forbidden region virtual fixtures (VFs)" (or 'virtual boundaries'), to assist with sorting tasks. Adult participants, one whom had cerebral palsy, performed the tasks with and without the VFs activated. For the participant who had CP, the VF condition was found to increase the completion time of two out of the three tasks, although the authors stated that customising the

VFs to each individual's requirements may overcome this issue.

Jafari et al. (2018) examined using a robot teleoperation system with haptic feedback to assist people who have CP with colouring activities. The virtual assistance condition was found to be "significantly more effective" when compared to unassisted and typical approaches.

The three previous studies included systems that required the user to grip and manipulate a hand-held end-effector. This is something that the TG are not able to do.

A number of studies have focussed on the use of haptic feedback in the rehabilitation of those who have disabilities. The Nintendo Wii© games console used a handheld wireless controller called a 'Wii-mote', which provided haptic feedback to the user during gameplay. The Nintendo Wii has been used within healthcare as a rehabilitation tool. This use is sometimes known as 'Wii-habilitation' or 'Wii-hab' (Rebecca The Physio 2015).

Deutsch et al. (2008) used a Nintendo Wii as a therapy tool with an adolescent who had cerebral palsy. The haptic feedback aspect of the Wii-mote was mentioned as an important feature of the device. The researchers noted improvements in almost all of the outcome measures.

Keates et al. (2000) demonstrated that haptic feedback can assist people who have disabilities in using "point-and-click" activities involving a computer mouse. Force feedback technology combined with a "gravity well" was found to improve the accuracy of participants, particularly the "more severely impaired". The study focused on adults who had Parkinson's disease, arthritis or those who had suffered a stroke. All participants had some degree of hand movement. Although not directly appropriate for the TG (they have little or no voluntary movement), the use of "gravity wells" and haptic feedback could assist eye gaze users with 'locking onto', and selecting onscreen targets, with the possibility of increasing accuracy.

2.11.2.3 Other relevant haptic studies

The most relevant area of wearable haptic technology to the context of this study concerns hand-based designs such as haptic gloves. Schwerdt et al. (2009) used haptic feedback as a feature of a 'colour detection glove' for the visually impaired. The glove detected colours underneath the hand and then translated these into haptic vibrations which the wearer could learn to decode as specific colours.

Many existing haptic feedback "gloves", especially the force-feedback variety, can be heavy and restrictive (Bouzit et al. 2002). Due to their complexity, they may involve protracted set up periods and require that the user remain very still whilst fitting takes place and during use. As with haptic jackets (Lee and Kwon 2000), such devices can be difficult to don and so are not well suited to those who have involuntary movement or stiffness in their limbs.

Martinez et al. (2016) created a low-cost "vibrotactile glove" for the purposes of examining whether it is possible to identify virtual 3D shapes using feel alone, i.e. without being able to see the shapes. The authors stated that in applications that “require users to manipulate one object while maintaining focus on another, such feedback” (haptic) “is essential”. A similar situation was likely to occur in the current study: the participant’s attention could be split between interacting with the user interface and surveying the scene to examine the results of their actions. Haptic feedback was used to provide both confirmation and reinforcement that an object was being ‘gripped’ (via the robotic arm) even if they were unable to see this.

Martinez et al. (2016) also highlighted that “Although the sensation is not equivalent to a natural sensation with real objects, the user soon learns to reinterpret it.” Sjöström (2001) also indicated that a haptic feedback sensation did not need to feel like something real in order to be effective. The use of haptic feedback in the current study was designed to provide an inexpensive rudimentary simulation of touch. Comfort and ease of attachment/detachment were prioritised over realism. Lee and Kwon (2000) noted that when designing wearable haptic technology for those who have disabilities it is important to use “sensors and actuators that are small, light, and attach simply”.

Martinez et al. (2016) also emphasised the importance of identifying a comfortable level of haptic feedback to prevent it from becoming fatiguing or from “saturating the touch channel”. This was considered to be especially important for the TG as there may have been a great deal of variation in tactile sensitivity between individuals.

2.11.3 Potential issues related to haptic feedback

2.11.3.1 Musculoskeletal loading

Kinaesthetic or “force” systems may increase musculoskeletal loading, especially if they resist the user’s movements. This is especially concerning for individuals who have involuntary movement (Jafari et al. 2016) as such movement may strain against resistive forces.

2.11.3.2 When used with the TG

When using hand-based haptic feedback technology with ‘able-bodied’ participants it would be useful to first establish the individual’s dominant side, specifically, their ‘handedness’ i.e. left or right. The participant could then use the haptic device with their dominant hand in order to experience a greater sense of ‘connection’.

However, Henderson and Pehoski (2006) highlighted that it can be difficult to establish the dominant side or “handedness” of children who have disabilities, and that tactile sensory abilities may be reduced. Wingert et al. (2008) adds that sensorimotor and somatosensory systems can also be affected.

Thus, “handedness” may be difficult to establish in the TG. Instead, it may be preferable to attempt to ascertain the hand in which they are most able to identify touch. This was attempted during the baseline/pre-test physical touch assessment of this study. It may also be the case that TG individuals have a ‘preferred’ or ‘more comfortable’ side. In the current study it was therefore decided that the participants should choose on which hand they would prefer to wear the haptic device.

As stated earlier, the TG’s ability to sense touch may be impaired. Some may experience hyper-sensitivity - being highly sensitive to even mild tactile sensations. Others may have ‘Tactile Defensiveness’ (Ayres and Tickle 1980), and display “adverse reactions” to tactile sensations, finding vibration sensations unsettling, uncomfortable or startling. Conversely, some may have hypo-sensitivity, and feel the sensation weakly, or not at all. As the TG were not able to remove the haptic device from themselves it was of high importance that any haptic sensation was safe, adjustable and that a comfortable sensation level was found for each individual.

2.12 Combinations of technology

A number of studies have used combinations of robotics, eye gaze and haptics.

2.12.1 Eye gaze control of robotics

Following the creation of the Erica eye-gaze system, Hutchinson et. al. (1989) stated the many possible applications where eye-gaze could be used as an input method. The authors suggested (and alluded to working on) controlling a mobile robot using eye gaze for children who have disabilities.

Shahzad and Mehmood (2010) created a prototype which provided control of a robotic arm using a simple eye gaze interface. Each joint of the arm could be manipulated independently. Whilst flexible, such an approach is slow and cognitively demanding for the operator. For the TG, a more suitable approach may be to position the arm’s joints automatically, based on the desired position of the end-effector (Davies 1995), i.e. the user is only concerned with positioning the arm’s ‘gripper’ – the position of individual joints would be calculated automatically.

In the above study, the user first selected an onscreen cell and then looked to the arm to see the results of this action. This could lead to unintentional selections or the ‘Midas touch’ (Jacob 1990) if the eyes continue to be tracked as the POR moves across the interface, or are ‘left behind’ i.e. the cursor stays in the last known position and repeatedly selects the cell beneath it. It also divides attention between the interface and the scene. Possible strategies to avoid such issues include briefly ‘pausing’ or ‘hiding’ the interface following a selection, or prohibiting repeat activations of a cell until it loses and regains focus. Ensuring that the onscreen interface is free of active controls nearest the side where the robotic arm is positioned would help to prevent accidental selections when the user is looking towards the robot.

Encarnação et al. (2016) enabled children who have disabilities to control both virtual and physical Lego Mindstorms robots in an inclusive educational setting. The participants were able to take part in education activities that were part of the standard curriculum. The authors found that the participants often had difficulties understanding the concepts of rotation and frame of reference, particularly in directing robots which were driving forwards towards them. The study provided features to control the robot either through the child's or the robot's frame of reference, whichever was most appropriate for the child's level of understanding. In an earlier study (Cook et al. 2012) colour coding was used to help participants to identify the robot's left and right sides.

The current study attempted to minimise frame of reference issues by providing controls which act in a Cartesian-like manner (see Figure 2.1 (2)) rather than a spherical-coordinate-like manner (see Figure 2.1 (1)). The user's diagonal-left offset position means that a rotation to the left could look to them like the robotic arm's gripper was also moving backwards (see Figure 2.1 (b) bottom-left). This is not the case with Figure 2.1 (b) bottom-right.

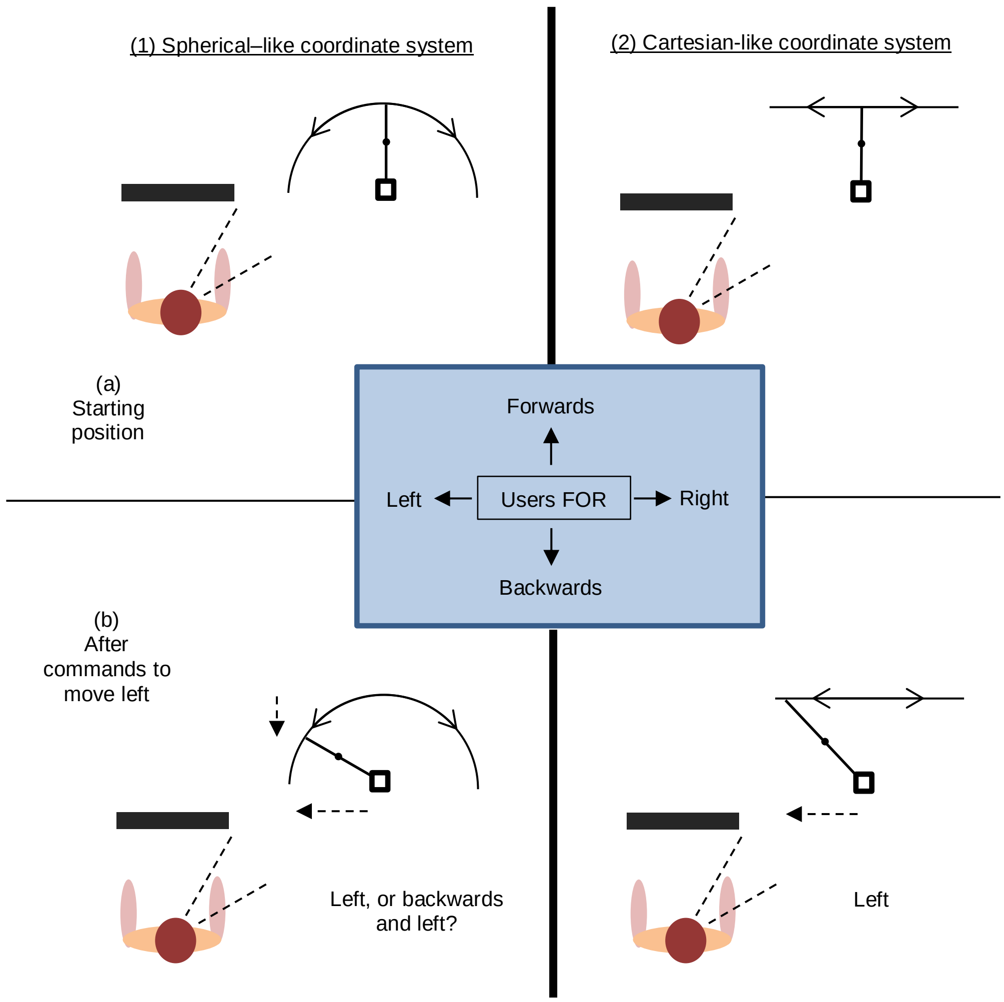


Figure 2.1 Avoiding frame of reference issues

Pasarica et al. (2016) used eye gaze to control a Lego Mindstorms robot using a head-mounted eye-tracking device. The user viewed a live video feed from the robot on a standard monitor and controlled the movement of the robot by focussing on different regions of the screen. The system had not been tested by anyone from their intended population at the time of the study publication.

2.12.2 Other forms of robotic control

Studies involving gaze control of other forms of robotics include wheeled vehicles (Tall et al. 2009) and Unmanned Aerial Vehicles (UAV's) (Hansen et al. 2014). In both of these studies the user interface included a live video feed from a camera positioned on the vehicle. The user interface contained no visible controls. Vehicle control was achieved by looking at regions of the screen, for example the user looks above the centre of the screen to move forwards, below to go back, left to go left and so on. Stopping, or remaining stationary is achieved by looking at the central section of the screen. With such a design, if the user wishes to look around the scene, they may encounter the 'Midas touch' (Jacob 1990) and accidentally trigger movements. In such cases, adding a feature to 'pause' gaze control would allow the user to inspect the scene without issuing commands. The TG of the current study is accustomed to using mainly visible controls. Using non-visible controls may have caused confusion. This approach was avoided in the current study.

Chern-Sheng et al. (2006) adapted a powered wheelchair so that it could be controlled using eye gaze. A user interface approach similar to those used in the studies above (Tall et al. 2009; Hansen et al. 2014) was used, but the control regions were positioned towards the edges of the gaze area. There are mapping issues with this design since the user needs to look up to move forwards – this could create disorientation as the user needs to look up to move, and then forwards to see where they are travelling. Travelling backwards involved facing forwards but looking downwards, which may raise safety concerns as the operator is unable to see what is behind them whilst doing this.

Also, with such approaches, care needs to be taken regarding obstacle avoidance strategies as the user may focus on obstacles that they wish to avoid, which would direct the path of travel towards the obstacle rather than around or away from it. Adopting this approach to control a robotic arm may be viable for left and right movements, but mappings for forwards/upwards, and backwards/downwards, may conflict.

Similar to the problems of eye gaze wheelchair control, selection of objects merely by looking at them may result in unintentional selections since not all eye-pointing is used to indicate intent (Sargent et al. 2013). Releasing objects would be similarly difficult using this approach. The current study aimed to enhance the TG's understanding of directions and so an approach which involved the movement of the robotic arm's end-effector up, left, forward and so on was considered to be preferable.

Latif et al. (2008) provided useful insights into user interface considerations required when designing for gaze-control in 3D environments. Of special note is that trapezoid shaped controls were sometimes used around the edges of the screen during a live camera view of the scene. This technique allows the user interface controls to be large (making them an easier target for the eye gaze user) whilst also ensuring the maximum amount of 'non-active' screen space and visibility of the live camera feed. A notable disadvantage of the design used in the study is that it used ‘modes’ to display different views and change between control modes, which Norman (2013) suggests may be confusing, even for experienced users.

2.12.3 Eye gaze and haptic feedback

Käki et al. (2014) demonstrated how haptic feedback can sometimes assist with gaze-controlled tasks. However, Rantala et al. (2014) found that haptic feedback does not always help and can sometimes cause confusion, or even annoyance. These conflicting results may indicate that further research is needed to identify the most appropriate approaches and use cases. The current study did not use haptic feedback to guide or enforce boundaries upon the user. Instead it provided the TG with a rudimentary simulation of ‘gripping’ to indicate and reinforce that ‘they’ were ‘holding’ an object.

2.12.4 Robotics and haptic feedback

A wide range of studies involving robotics (and haptic technology) have focussed on rehabilitation, in particular for individuals who have a paretic upper limb following a stroke. A number of these studies are reviewed in Brewer et al. (2007), Kwakkel et al. (2008) and Babaiasl et al. (2016). The systems described typically focus on assistance, resistance and guidance, with the aim of motor relearning and restoring function. The present study was not concerned with restoring function, but with matching and customising technology to fit the PPs’ abilities to enable them to perform activities.

The system in the current study is similar to a ‘teleoperation’ system, whereby a ‘slave’ robot is commanded by the user which then feeds back information to the user (Stone 2001; Jafari et al. 2016). The TG did not directly touch any real physical objects with their own hands during the present study, but ‘touched’ objects indirectly through intentional manipulation of the robotic arm i.e. commands were sent (via eye gaze) to the ‘slave’ robotic arm which gripped an object and then conveyed this back through haptic feedback (as well as visually and using auditory feedback).

Tachi (2016) explains how remote sensors on a robotic hand and a haptic glove on a person’s hand can contribute to giving that person a sense of “telexistence” i.e. feeling as though they are physically and spatially in a different location to their current one. The system used provided a variety of tactile sensations using a combination of force, vibration and temperature, to mimic different properties of objects. Tachi emphasised the potential opportunities for people who have disabilities to be “present” (at another location) without even leaving their homes.

Tachi (2016) highlights the importance of feeling “spatially present” when performing a remote-controlled operation and that telepresence systems often lack this. This may also be a benefit of a physical over a virtual system. The user may have a more ‘connected’ feeling when the physical equipment that they are controlling is near to them.

Conversely, if the robotics were in another room or virtual, it may be less distracting for the user. They would only need to attend to the screen rather than alternating between a screen and a real scene. The current study did not aim to build such an elaborate system as Tachi's, but aligns in its aim of using vibrating or 'vibrotactile' haptic technology.

2.13 Summary

The foregoing review of the literature reveals a number of pertinent points. Conventional assessment methods are unsuitable for the TG, and there are few suitable alternatives described within the literature. AT research has demonstrated that assistive robots can be used to enable those who have impairments to engage in experiences that they cannot have otherwise. These experiences include object manipulation, playing with toys, education and art. Assistive robots have also been shown to offer an alternative method for revealing the knowledge and skills of those who are difficult to assess by other means. Haptic technology can be used to provide an additional information channel for those who may not be able to use touch in the conventional manner due to motor impairments. Many prior studies which involved individuals similar to the TG have been hampered by user interface (UI) issues often relating to using scanning as an access method. The advent of eye gaze technology has provided a direct access method for such users enabling direct and easier to map UIs.

2.14 Overall gaps identified within the literature

The current study was motivated by the following apparent knowledge gaps identified in the literature:

- **Assessments.** The TG is currently a particularly difficult group for clinicians / therapists to assess both physically and cognitively. Existing assessment approaches are unsuitable for the TG. Cognitive assessments rely heavily on pointing to or verbalising answers, both of which the TG cannot do.
- **Haptic feedback.** Many systems described seem only to provide visual and auditory feedback to the user. Haptic feedback is particularly important for the TG as they lack self-initiated tactile experiences. No existing studies concerning the use of haptic feedback technology with those who have the characteristics of the TG were found. No studies were located which directly related to the purposes of the current study i.e. delivering haptic sensations to the hands of the TG in order to create a sensation of gripping an object. The haptic devices described within the literature would not be suitable for use with the TG.
- **Eye gaze and robotics.** Only one study was found which described the use of eye gaze technology to control robotics by individuals who are similar to the TG (Encarnação et al. 2016). However, the robotics used were in vehicle not arm form, and no haptic devices were used (to reinforce the experience of manipulating physical objects).
- **A shortage of suitable robotic systems for the TG.** In particular a lack of a robotic-

based system which uses eye gaze control of a robotic arm with haptic feedback for use by the TG. Cook et al. (2010) called for appropriate robotic systems for use with CYP who have disabilities. There are few studies linking eye gaze and the control of robotic arms, and none were found which combine eye *gaze*, robotic arm control and haptic feedback with a focus on providing the TG with physical control and play opportunities. Studies have identified that using robotics with young people who have disabilities can be beneficial to those groups. Haptic feedback has also been shown to assist those who have disabilities. This study was designed to unite both of these technologies and investigate how the benefits may be combined.

- **Orientation of the robotic arm.** In the studies located which described the use of robotic arms, the orientation was usually an 'overhead'/'upside-down' arrangement (see Table 2.2 (a)) when compared to a relaxed human arm i.e. hanging by the side of the body (see Table 2.2 (b)). There is a danger that using robotic arms in the standard 'overhead' configurations, with people who may already have a distorted body image, may lead to body dysmorphia or confusion.

To summarise, this research aimed to address the above gaps by creating new assessments and designing a system involving the following technologies: eye gaze, robotics and haptic feedback, which was used by the TG to solve a series of tasks.

Chapter 3 Research Methodology

3.1 Introduction

The research process is complex. The literature describes a variety of different approaches and associated terminology relating to this process (Saunders et al. 2015). Crotty (1998) states that there are a "bewildering array" of methodologies and methods available, and that the associated terminology is often used "in a number of different, sometimes even contradictory ways".

In order for academic research to be carried out in a systematic and rigorous manner it is important to understand and establish the approach and methods used from the outset. This section outlines and discusses various approaches to conducting academic research and the rationale behind those chosen for this study.

3.2 Outline of research methodology

Table 3.1 provides a high level overview of the research methodology adopted for this study. This will be explained in detail in the remainder of this section.

Table 3.1 Research approach – Summary

Applied or Basic	Applied
Philosophy	Pragmatism
Approach to theory development	Inductive and Deductive
Methodological choice	Mixed Methods (simple)
Strategy(ies)	Experiments
Time Horizon	Within-subjects design (two points in time)
Techniques and procedures	Tasks, training, observation, quantitative and qualitative data gathering

3.3 Methodology

3.3.1 Applied or Basic research

This section describes the first choice to be made when carrying out a research project.

Collis and Hussey (2014) state that there are two broad forms of academic research: 'Applied' and 'Basic'. **Applied** research "describes a study that is designed to apply its findings to solving a specific, existing problem" (Collis and Hussey 2014, p.6), whereas **Basic** research (also known as fundamental or pure research) "describes a study that is designed to make a contribution to general knowledge and theoretical understanding, rather than solve a specific problem" (Collis and Hussey 2014, p.6). Saunders et al. (2015) describe a research "continuum" with Basic and Applied at either end. Research projects are said to be placed somewhere between the two.

This research is positioned towards the 'Applied' end of the continuum, since it focuses on "solving a specific, existing problem" (Collis and Hussey 2014, p.6) i.e. the TG have limited opportunities to engage in self-directed physical activities. This study aimed to provide more opportunities in this area.

The next decision concerns the overall approach to the research and the model followed. Saunders et al.'s (2015) research 'onion' provides one possible representation (see Figure 3.1), which includes a visualisation of the research process. This approach illustrates the many different facets of the process and the relationships between the various parts or 'layers'.

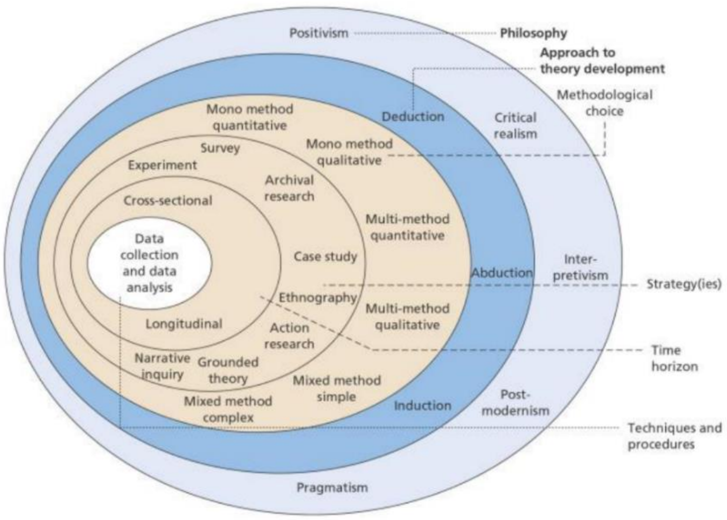


Figure 3.1 The Research Onion (Saunders et al. 2015)

This model will be used as the basis to aid an explanation of the research process and the approaches used within this study. Working from the outer to the inner, the 'layers' of the model are:

(1) **Philosophy:** the beliefs and assumptions held about knowledge development.
(2) **Approach to theory development**: how theories are generated: from the outset (*deductive*) or built from the data collected (*inductive*).
(3) **Methodological choice**: influenced by whether the research needs to capture quantitative, qualitative or a mixture of both forms of data.
(4) **Strategy(ies)**: the plan of action that will be used to achieve the research goals (Saunders et al. 2015).
(5) **Time Horizon**: the duration of the research and the number of points at which data will be gathered.
(6) **Techniques and procedures**: the actual data gathering and analysis tools.

These 'layers' will now be described in turn, as they relate to the current study, starting with the outer layer (Philosophy) and moving inwards through the layers towards the centre (Techniques and procedures).

3.3.2 (Layer 1) Philosophy

3.3.2.1 Philosophy, paradigms and worldviews

Saunders et al. (2015, p.124) state that the term 'research philosophy' "refers to a system of beliefs or assumptions about the development of knowledge". These beliefs and assumptions are said to shape the way that research is carried out, affecting all stages of the process from the choice of methodology through to the data collection techniques used. Creswell and Plano Clark (2011) prefer the terms 'philosophical assumptions' and 'worldviews'. Collis and Hussey (2014) use the term 'paradigm', describing a paradigm as a 'philosophical framework'.

The main philosophical approaches will now be explained, after which will follow a discussion of the 'beliefs and assumptions' associated with these approaches.

3.3.2.2 Main philosophical approaches

Collis and Hussey (2014) describe two main research 'paradigms', **Positivism** and **Interpretivism**:

Positivism: "The philosophical stance of the natural scientist entailing working with an observable social reality to produce law-like generalisations. The emphasis is on highly structured methodology to facilitate replication." (Saunders et al. 2015, p.724).

Interpretivism: "A philosophical stance that advocates humans are different from physical phenomena because they create meanings. Argues that human beings and their social worlds cannot be studied in the same way as physical phenomena due to the need to take account of complexity." (Saunders et al. 2015, pp.718-719).

Positivism is said to be largely concerned with hypothesis testing and quantitative data, with a focus on repeatability and objectivity. In contrast, **Interpretivism** is said to be more focused on lived experiences, meaning, qualitative data, and is said to be subjective.

Collis and Hussey (2014) emphasise that positivism and Interpretivism are not "polar opposites", but "extremities of a continuous line of paradigms that can exist simultaneously".

Collis and Hussey (2014) also describe a third paradigm, '**Pragmatism'**, which is positioned somewhere between Positivism and Interpretivism on the continuum and allows elements from the spectrum of paradigms to be used, as required, to suit the needs of the research. Pragmatism acknowledges that both Positivist and Interpretivist approaches have strengths and value in situations which require both quantitative and qualitative methodologies.

Creswell and Plano Clark (2011) state that the Pragmatist worldview is "problem centred" and "real-world practice oriented". This view is echoed by Saunders et al. (2015) who state that Pragmatism puts "emphasis on practical solutions and outcomes" (Saunders et al. 2015, p.137) and “starts with a problem and aims to contribute practical solutions that inform future practice” (Saunders et al. 2015, p.143).

3.3.2.3 Pragmatism and its relevance and suitability for this research project

The research philosophy adopted by this study is **Pragmatism**, as the research problem emerged through practice-based work i.e. the researcher’s profession as an Assistive Technologist; the research outputs are intended to ‘solve a problem’ i.e. to enable the TG to engage in activities which are not available to them currently; and to contribute to future practice by providing a tool to assist the TG’s development.

Both quantitative and qualitative data were gathered. The study included a small number of TG participants who were complex in nature. Data was captured about the TG participants’ level of knowledge (quantitative) but also about their experiences of using the intervention (qualitative), in order to create a richer and deeper understanding of the group.

The investigator has worked with members of the TG over the past thirteen years and was a participant and an integral part of the research, carrying out sections of the assessment and intervention stages (see Assessment Design and Administration chapter and Intervention Design and Administration chapter). Due to the existing relationship between the TG participants and the investigator and the highly complex nature and vulnerability of the TG, a detached, objective (positivist) stance would not have been possible. It is inevitable that the investigator’s involvement would have affected the behaviour of the participants being studied and that the research influenced the investigator.

3.3.2.4 Beliefs and assumptions

At the beginning of this ‘Philosophy’ section, it was stated that a research philosophy “refers to a system of beliefs or assumptions about the development of knowledge” (Saunders et al. 2015, p.124). These beliefs and assumptions are said to be categorised as **ontological**, **epistemological** and **axiological** (Saunders et al. 2015). These terms will now be explained and then related to the main philosophies to illustrate how they differ between the approaches:

- **Ontological**: Relating to the nature of reality. The study of ‘being’, “of the essence of phenomena and the nature of their existence” (Gray 2013, p.19).
- **Epistemological**: This refers to the assumptions that are made about knowledge – what is considered to be acceptable, valid and legitimate knowledge.
- **Axiological**: Concerning values and ethics – this relates to those of both the researcher and the participants.

As stated, different research philosophies hold different views on each of these.

Table 3.2 shows how these beliefs and assumptions differ between the two main paradigms of Positivism and Interpretivism (Collis and Hussey 2014).

Table 3.2 Adapted from Collis et al. (2014)

Philosophical assumption	Positivism	Interpretivism
Ontological assumption (the nature of reality)	Social reality is objective and external to the researcher.	Social reality is subjective and socially constructed.
	There is only one reality.	There are multiple realities.
Epistemological assumption (what constitutes valid knowledge)	Knowledge comes from objective evidence about observable and measurable phenomena.	Knowledge comes from subjective evidence from participants.
	The researcher is distant from phenomena under study.	The researcher interacts with phenomena under study.
Axiological assumption (the role of values)	The researcher is independent from phenomena under study.	The researcher acknowledges that the research is subjective.
	The results are unbiased and value-free.	The findings are biased and value-laden.

Pragmatism incorporates elements of the beliefs and assumptions of both Positivism and Interpretivism, depending upon where the project is positioned on the continuum.

3.3.3 (Layer 2) Approach to theory development

Theories can be developed at the beginning of the research process and then tested during the research (**Deductive**). Theories may also be built from the research findings in order to explain patterns or relationships, or to link to existing theory (**Inductive**).

Saunders et al. (2015) provide definitions for deductive and inductive approaches to theory development:

- **Deductive:** "…involving the testing of a theoretical proposition by the employment of a research strategy specifically designed for the purpose of its testing." (Saunders et al. 2015, p.714).
- **Inductive:** "…involving the development of a theory as a result of the observation of empirical data." (Saunders et al. 2015, p.718).

Gray (2013) posits that Inductive and deductive processes are "not mutually exclusive". This study used a combination of deductive and inductive approaches at different stages of the research:

Deductive theory development: It was hypothesised that the intervention would influence the TG's understanding of the physical world in measurable ways. The assessment stage of this research (see 3.3.5) was designed to measure these changes i.e. assessing the knowledge and understanding of the TG participants both before and after the intervention stage, and then comparing the results.

Inductive theory development: The observations that took place during the intervention stage revealed information about the strategies employed by the TG and the difficulties encountered in completing specific tasks i.e. the TG participants' behaviour was observed while they used the system, and the findings explained descriptively using both existing and new theory.

3.3.4 (Layer 3) Methodological choice

The methodological choice refers to the process of data collection. The methodological choice for this study is '**mixed methods**', which involves the collection of both quantitative and qualitative data. A **quantitative** approach is concerned with gathering "Numerical data or data that have been quantified" (Saunders et al. 2015, p.725) and this approach is most often associated with Positivism. **Qualitative** research involves the collection of "non-numerical data or data that have not been quantified" (Saunders et al. 2015, p.724) and this approach is most often associated with Interpretivism. A Mixed Methods approach advocates the use of "both quantitative and qualitative data collection techniques and analysis procedures either at the same time (concurrent) or one after the other (sequential)" (Saunders et al. 2015, p.720).

As stated in the (Layer 1) Philosophy section, this study adopted a research philosophy of 'Pragmatism' which, according to Creswell (2013) is typically associated with a mixed methods methodology.

The pre and post-test stages of this research (see 3.3.5) focussed on assessments and the collection of quantitative data. The intervention stage included the collection of quantitative data, for example, the time taken to complete a given task, but also qualitative data, for example how the participant behaved during the intervention tasks.

3.3.5 (Layer 4) Strategy

The research strategy refers to the plan of action to achieve the research goals (Saunders et al. 2015). To achieve the research goals within this study, the strategy used from within the research 'onion' was 'Experiment'.

This research used a type of experiment design known as 'within-subjects' or 'within-group' design (Saunders et al. 2015). The use of a within-subjects design is appropriate when the number of possible participants is small, as it does not require a control group, only an experimental group. In a within-subjects design the subjects act as their own control; measures are taken before and after being exposed to an intervention; they are then compared with their 'former selves' to identify any impact from the intervention. This design takes the form of:

- Pre-test or pre-intervention observation or measurement to establish a baseline (or control for the dependent variable);
- A planned intervention (the independent variable);
- Post-test or subsequent observation (outcomes) and measurement (related to the dependent variable).

A within-subjects design was suitable for this research and for the TG sample for the following reasons:

- The TG sample was small (only two pupil participants), which precluded the possibility of both an experimental group and a control group. The chosen design required no control group, only an experimental group;

- The main aim of the experiments in this research was to establish what impact, if any, use of the intervention had upon the TG, regarding those factors assessed in the pre and post-tests, and also from the observations;
- Every participant was exposed to the planned intervention;
- There is considerable variation within the TG in terms of level of ability and understanding. The performance of each of the TG participants in the pre and post-tests was compared against themselves. The pre-test or baseline was their starting point, and was the benchmark against which their post-test or outcomes performance was compared.

The main disadvantage of this design is:

- It was difficult to control for confounding variables: it was possible that a TG participant may have improved their score in the post-test stage not necessarily because of the intervention, but because they had learned some of the same concepts within their school education or through other means occurring simultaneously.

The experiment was designed to capture both quantitative and qualitative data. The assessments gathered quantitative data, whereas the intervention captured both quantitative and qualitative data. Video recordings were made during the intervention, which were subsequently analysed.

3.3.6 (Layer 5) Time Horizon

The duration of a research project can be relatively short or may extend over many years or even decades.

Data gathering may occur at several points over a period of years (longitudinal), or may be cross-sectional, whereby a ‘snapshot’ is taken at a specific point in time. The ‘within-subjects’ design gathers data before and after the introduction of an intervention, or series of interventions.

This study had a limited timeframe and so a longitudinal approach was not possible. A cross-section approach would not have revealed any possible effects from the introduction of the intervention. The ‘within-subjects’ approach enabled two measurements to be taken, which allowed comparison between pre and post-test measures.

3.3.7 (Layer 6) Techniques and procedures

This ‘layer’ involved the actual data collection and analysis processes. Data was collected using bespoke assessment tools, the completion of various participant tasks and also through the use of observation techniques. The concepts under investigation are detailed in Appendix B.

3.3.7.1 Data collection and data analysis

As the number of 'pupil' participants was small, and to avoid the 'learning effect', elements of the assessment stages and intervention were first trialled by staff participants, before being used with the TG participants.

Data collection and analysis took place over four stages (Figure 3.2). The TG sample was assessed before and after the intervention was introduced, and the results analysed in order to identify any impact from the intervention. There now follows an overview of the stages followed by more detailed descriptions:

(1) **Pre-tests (Baseline measures):** Data collection commenced with several pre-tests (assessments) of the TG sample:

- Assessment of existing knowledge of specific physical and spatial concepts;
- Physical touch assessment;
- Haptic sensations assessment.

(2) **Planned Intervention:**

- The TG sample were trained in how to use the robotics-based system;
- The TG sample used the robotics-based system to complete a series of tasks.

(3) **Post-tests (Outcome measures): A repeat of the pre-tests:**

- Assessment of knowledge of specific physical and spatial concepts;
- Physical touch assessment;
- Haptic sensations assessment.

(4) **Analysis of pre-test, planned intervention and post-test data:** The pre and post-test findings were compared and the data generated from the intervention stage was examined:

- **Pre-test/post-test:** Assessment results from before and after the planned intervention stage (quantitative) were compared.
- **Physical touch and haptic sensations:** The results from the physical touch and haptic sensations assessments, both before and after the introduction of the intervention (quantitative), were compared.
- **Intervention:** Data from the experiments (quantitative) and observations (qualitative) was analysed to identify themes that may have emerged during the intervention stage.

The above stages (1 – 4) will be discussed in greater detail in the sections that follow.

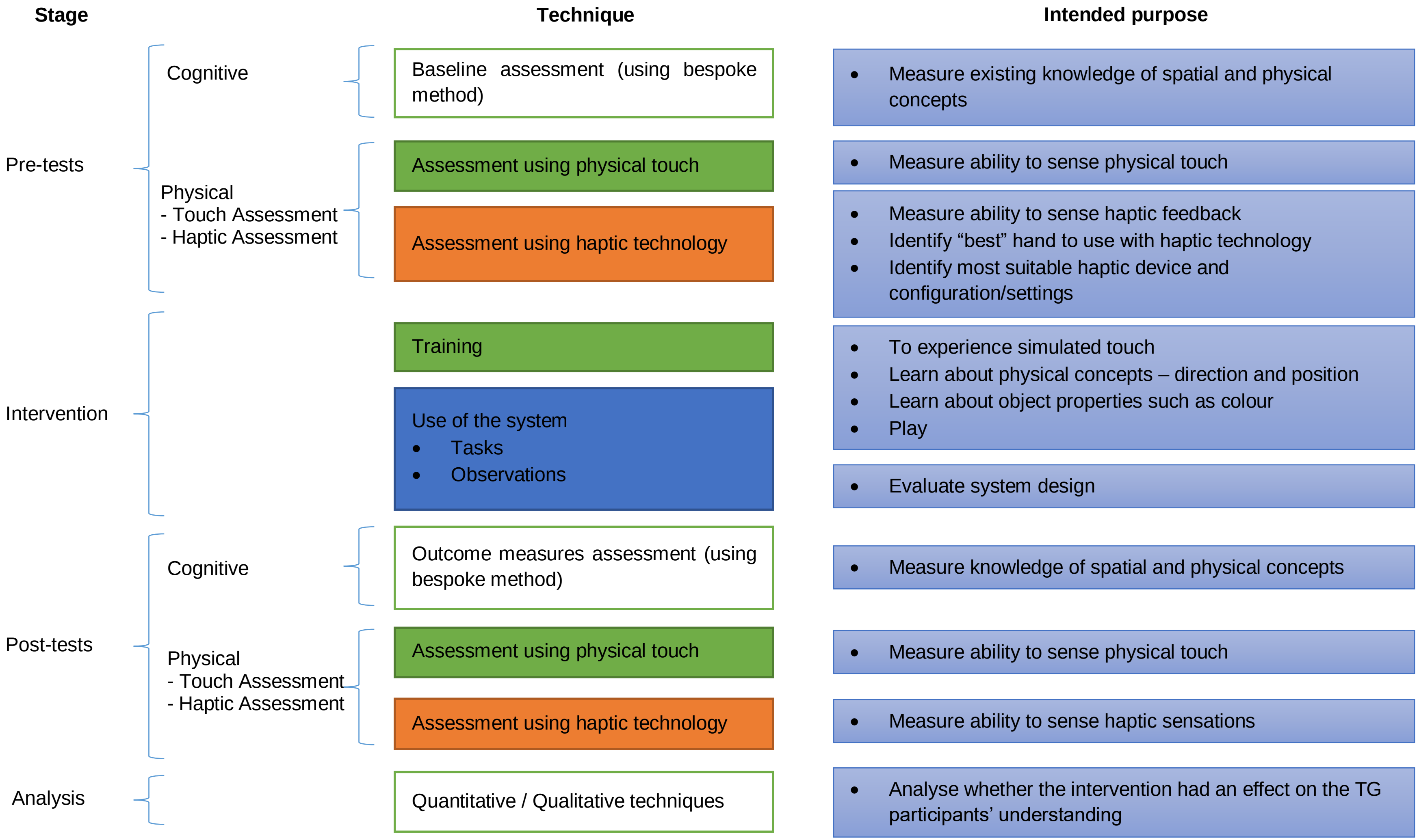


Figure 3.2 Data collection and analysis

(1) **Pre-tests (Baseline measures)**

An initial battery of pre-tests helped to establish a baseline, identifying the current level of knowledge, understanding and ability of the TG sample. These same tests were repeated after the intervention stage in the post-test stage.

1.1 Assessment of physical and spatial concepts

The purpose of this assessment stage was to establish the TG sample's current level of knowledge and understanding of physical and spatial concepts. This included their ability to correctly identify colours, directions and concepts relating to position such as above and below, behind and so on. This assessments were carried out using bespoke software assessments.

1.2 Physical touch assessment

An assessment was performed with the TG participants to ascertain how well they could identify physical touch sensations in their hands (see Assessments Design and Administration chapter). Each TG participant underwent a series of trials. Each of these trials involved the physical touching of their left, right, neither, or both of their hands. In each case, the participant was asked to indicate what they thought had happened.

1.3 Haptic sensations assessment

Prior to the haptic assessment, the most suitable haptic device was chosen from a range of prototypes by the staff participants. This selection was guided by the characteristics of the PP's disability and physical characteristics, for example, involuntary movement or tight hands.

An assessment, very similar in format to the physical touch assessment, was then performed with the TG participants. This time instead of physical touch, the 'touch' sensations were delivered using haptic technology.

The physical touch and haptic assessments were designed to produce quantitative data i.e. the number of correct/incorrect identifications. Descriptive statistics techniques were used to analyse and present this data.

(2) **Intervention**

The intervention included training (recommended by Adams and Encarnação (2011)), use of the robot-based system, and completion of a range of structured tasks. These stages of the intervention were introduced to the TG participants over a number of sessions. Informal training was given in how to use the system, but also about colour, directions and position, if needed.

The tasks became progressively more challenging over time i.e. the difficulty level or number of stages required to complete a given task increased over time. As the number of task stages increased, the level of system autonomy decreased while the user autonomy increased.

The intervention stage generated both quantitative and qualitative data. Examples of quantitative data include: whether the TG participants were able to complete a given task and the time taken to do this. Examples of qualitative data include: how the TG participant approached task completion, and observations about their behaviour. Video recordings of the sessions were made and an observation schedule used to identify themes and patterns.

(3) **Post-tests (Outcomes) measures**

This stage involved a repetition of the assessments performed under the Pre-tests stage.

3.1 Assessment of physical and spatial concepts

The same assessment was used as in the Pre-test – Assessment of physical and spatial concepts stage. The purpose of repeating this assessment was to re-examine the TG participants' level of knowledge of the concepts under investigation to see whether changes had taken place as a result of the intervention.

3.2 Physical touch assessment

The same assessment was used as in the *Pre-test – Physical touch assessment* stage. The assessment was repeated with the TG participants to ascertain how well they could identify physical touch sensations in their hands (see Assessment Design and Administration chapter) and whether this had changed since the Pre-test stage.

3.3 Haptic assessment

The same assessment was used as in the Pre-tests (Baseline measures) section. The assessment was repeated to examine whether the TG participants' ability to sense haptic sensations in their hands had altered since the Pre-test stage.

The physical touch and haptic assessments were designed to produce quantitative data i.e. the number of correct/incorrect identifications.

(4) **Analysis of pre-test, intervention and post-test data**

Analysis involved the examination of the quantitative data generated during the pre and post-test stages. The two sets of data were compared and any differences noted.

The data generated during the intervention stage, from observations and TG participant trials, was examined and the findings analysed and discussed.

The data has been summarised using a range of descriptive statistical methods i.e. graphical and textual descriptions. Explanations have been sought for patterns and themes which emerged from the data.

3.4 System Usability

The usability of the system was evaluated using the NASA Task Load Index (NASA-TLX) and the System Usability Scale (SUS).

3.4.1 NASA-TLX

NASA-TLX (National Aeronautics and Space Administration (NASA) 2019) was used within this study to rate the workloads experienced by SPs and PPs when using the robotics-based system.

NASA-TLX is a freely available subjective workload assessment tool. It contains six subscales (Mental Demand, Physical Demand, Temporal Demand, Performance, Effort and Frustration) against which ratings are given on a scale of 0 to 100 in increments of 5 (see Appendix H). It has been used in various environments, including aircraft cockpits.

Usually, NASA-TLX forms are completed by the individual after completing a task. It was not possible for the PPs to complete the forms in the present study and so a different approach was adopted. After a PP had completed a task, or tasks, a Learning Support Assistant (LSA) who knew the PP well would complete a NASA-TLX form on behalf of the PP, providing proxy ratings of the workload that they perceived the PP would be experiencing.

NASA-TLX also has a ‘weightings’ component which allows subjects to attach greater importance to particular subscales, depending upon which they considered contributed most to the task workload. The weightings element was omitted in the present study, as the intention was to identify which subscales had the highest ratings and not the order of importance of the subscales themselves, and to simplify the evaluation process.

3.4.2 SUS

The System Usability Scale (SUS) (Brooke 1996) provides a “quick and dirty” method of evaluating the overall usability of a system. The scale contains 10 statements against which ratings are given on a five point scale ranging from ‘Strongly disagree’ to ‘Strongly agree’ (see Appendix J).

In the present study, the SUS was used to obtain SP ratings of the usability of the robotics-based system with the purpose of improving the system before being used by the PPs.

3.5 Study site and participants

3.5.1 Study site

This research was carried out at Livability Victoria Education Centre (VEC) in Poole, Dorset. The author of this report has been employed at the Centre for the past thirteen years as an Assistive Technologist.

3.5.2 Ethical approval

Ethical approval was granted by the Science, Technology and Health Research Ethics Panel of Bournemouth University. The ethical approval and participant consent and assent documentation for the study can be found in Appendix X.

3.5.3 Participants

This study formed a pilot to establish the potential of using the research outputs, described later, with larger groups of participants from the TG.

Both pupils and staff from VEC participated in this research. SPs were involved in creating some of the assessments as well as evaluating elements of the assessments, haptic prototypes and intervention, and informing and improving the study design. A description of the TG and PPs, who are the main focus of this research, now follows.

3.5.3.1 Population and sample

The **total** population is the group of young people who match the inclusion criteria (see 3.5.3.2). This study did not have access to the **total** population. The **sample** population is a subset of the **total** population. This subset consisted of VEC pupils who met the inclusion criteria (see next section). A total of three pupils met all of the inclusion criteria, of which two assented to participate.

A convenience sampling technique was used i.e. convenient to the researcher. The researcher and the research was based at VEC and so had access to the staff and pupils there.

The statistics presented in this thesis are to provide information regarding the performance of just two individuals. With so few PPs taking part in this study it is not possible to attribute statistical significance to the results. For this to be achieved, a much larger sample would be needed, but even so, the heterogeneity of such populations means that inferences and generalisations from the results should be made with caution.

3.5.3.2 Inclusion criteria

Pupils who met all of the following inclusion criteria were eligible to participate in this research study:

- Were attending VEC at the time of the data gathering phase and;
- Were affected by profound physical disabilities - GMFCS Level IV/V (Palisano et al. 2007);
- Had 'good' cognition - they had attained a minimum of SEN P scale level 6 in Mathematics, English and Science (Department for Education 2017);
- Had complex communication needs i.e. they both had complex communication difficulties and were non-verbal;
- Were users, or had experience of using eye gaze technology for any of the following: communication, environmental control or computer control;
- Had limited opportunities to engage in physical interaction and play.

Both the parents and the young people were asked for their consent and assent. The PPs were asked for assent using a specially designed symbolised Participant Information Sheet (PIS) (see Appendix X).

3.5.3.3 Exclusion criteria

Pupils were excluded from participating in the study if they:

- Had visual impairments that may have affected their ability to use an eye gaze system;
- Had hearing impairments that may have affected their ability to follow instructions whilst performing a task;
- Had cognitive impairments that would limit their understanding of the activities.

3.5.3.4 Pupil participants (PPs)

Two pupils elected to take part in the study: both were male; PP1 had a diagnosis of athetoid cerebral palsy; PP2 had a diagnosis of post-viral cerebral palsy; PP1 was aged 16 years 7 months, and PP2 was 19 years and 6 months at the time of the baseline assessments; neither had any verbal expressive language, but both were able to vocalize and had clear “Yes/No” responses; both were very experienced in using eye pointing for symbol-based communication (both low-tech using a communication book and a communication partner, and high-tech using eye gaze technology and dwell-select).

PP1 was at GMFCS level V and PP2 at VI/V (at the time of the study he was learning how to control powered mobility using a head switch).

Cognitive age is difficult to establish as assessment techniques are unsuitable for this group. However, for PP1 an adapted version of the British Picture Vocabulary Scale 3 (BPVS3) (Dunn et al. 2009), yielded an approximate age equivalent value of 6 years 2 months (September 2016).

PP2 was also assessed using an adapted form of BPVS3 in July of 2013 with an age equivalent score of 5 years and 4 months. The assessment was last attempted in May 2015, but the test was abandoned as PP2 repeatedly selected the same cell. He was not assessed subsequently.

According to PP1's SaLT, BPVS3 is considered a good measure of underlying cognitive ability but is likely to be an underestimate when used with the TG.

3.5.3.5 Staff Participation

This research received input from two categories of staff. One group consisted of a team of SaLT **advisers** for the cognitive assessments. The other group were Staff Participants (**SPs)** who trialled the outputs of the research prior to them being used with the PPs.

The SaLT advisors helped with refining the assessment administration procedures and gave feedback on content ideas which helped inform the final choices that would be presented to the PPs.

All of the staff involved in this study were female. They came from a range of professions within teaching and therapy, with experience ranging from approximately 5 to 37 years. The profile of the SaLT advisers is shown in Table 3.3 and the profile of the SPs is shown in Table 3.4.

Table 3.3 Professional experience of the SaLT advisers

SaLT No.	Years of professional experience (at the time of the study)
1	30
2	12
3	37
4	7
5*	18

* Not a VEC employee

Table 3.4 Profile of the SPs

SP No.	Profession/ Occupation	Years of professional experience (at the time of the study)
1 / LSA 1	LSA	7
6	Teacher	20 (e)
7	SaLT	12
8	Senior LSA	5 (e)
10	Teacher	33
12	OT	5 (e)
14	SaLT	29
15	Teacher	19
17	PE teacher	15 (e)
19	OT	19
27	Physiotherapist	32
25 / LSA 2	LSA	6

(e): Estimates are due to the individuals having now left the employment of VEC

VEC does not have records of what and how much experience staff have of AT. The level of AT knowledge possessed by each member of staff varies depending upon profession or occupation, number of years of professional experience and the pupils worked with. All therapy and teaching staff will have been exposed to various forms of AT during their work at VEC and have received greater exposure to AT, compared with the general public.

Pupils and staff at VEC utilise a wide range of AT. VEC has pupils who use high-tech communication aids, some of which include eye gaze technology, and alternative access peripherals such as touch screen devices, joysticks and trackballs. The Centre has environmental control and sensory rooms. A range of accessible music technology is used by the pupils, including the SoundBeam (Soundbeam 2015).

3.6 End of chapter Summary

This chapter has described the various stages of the research process and the decisions made for this study. In summary, this investigation used the approaches highlighted for each of the 'layers' in Table 3.5.

Table 3.5 Research Methodology overview: Adapted from Saunders et al. (2015)

Philosophy	**Approach to theory development**	**Methodological choice**	**Strategy(ies)**	**Time horizon**	**Techniques and procedures**
1	**2**	**3**	**4**	**5**	**6**
Positivism	Deduction	Mono method quantitative	Experiment	Cross-sectional	Data collection and data analysis
Critical realism	Abduction	Mono method qualitative	Survey	Pre/post	
Interpretivism	Induction	Multi-method quantitative	Archival research	Longitudinal	
Post-modernism		Multi-method qualitative	Case study		
Pragmatism		Mixed method simple	Ethnography		
		Mixed Method complex	Action research		
			Grounded theory		
			Narrative inquiry		

Chapter 4 Identifying the TG requirements of AT

4.1 Introduction

This chapter describes the process by which the requirements of the robotics-based system and the haptic device created for this study were elicited. It presents the approach and key requirements which were identified. This stage informed the technical implementation stage.

4.2 Systems development method

When developing hardware and software products it is rarely advisable to follow a 'one-size-fits-all' approach. Disability affects each individual differently. For this reason, a flexible approach is needed. Solutions need to be user centred, and sometimes designed for a specific individual (Cook and Polgar 2014).

Cook and Polgar (2014) present the Human Activity Assistive Technology (HAAT) model which can be used for developing AT solutions. The model describes someone (**H**uman) doing something (**A**ctivity) in a *context* using **AT**.

The HAAT model used in the context of Assistive Robots (Cook et al. 2010) has been adapted for this study and consists of:

The **<u>H</u>uman**, the **<u>A</u>ctivities and the <u>AT</u>:** CYP with motor disabilities (**H**uman) engaging with objects and play and academic activities (**A**ctivities) using robot-assisted manipulation (**AT**) for exploring, discovering and altering the environment. The *context* is a special education school.

Cook et al. (2010) state that the robot should be flexible enough to allow for a wide range of activities and activities should be developed only by considering user needs and preferences, not by the constraints of the technological solution.

The skills the person has for participating directly in the activity and for controlling the interface to the robot should also be considered. The envisioned activities, contexts and anticipated human skills should then determine the required technological capabilities and characteristics of the robot.

Cook et al. (2010) defined a set of desirable characteristics for assistive robots for CYP who have motor disabilities: The robot should be **reliable**, so as not to "frustrate and disengage" users and to ensure increased independence. **Safety** is key to ensure children are never harmed. User and Human-Robot interfaces should be **intuitive** and **accessible** for children who have a variety of different disabilities. They should be **easily learned** and **comfortable to use**. They should empower the user by providing effective control over the system and environment in a natural manner and provide appropriate **feedback**. Some **automation** may be necessary, with initially high robot **autonomy** and the system relinquishing this autonomy to the user over time, as their ability to control the robot increases with experience. The authors recommend incorporating a system **logging** function to “assess possible learning effects from the robot use”. They also note that the robots should be **aesthetically pleasing** to children to encourage them to use them and that they should be **low-cost** to make them available to many.

All of these considerations were at the forefront of the design of the robotic system used within this study.

This model shaped the requirements, design and development of both the technology and the tasks (**A**ctivities) used in this study.

The approach used looks at the characteristics of existing systems and those of the TG to identify gaps between the two. It looks at the perceived needs of the TG and the skills and abilities that they have to operate systems. Through this process, a set of requirements was created.

4.3 Requirements elicitation

Often, when designing systems, the ‘customer’ would provide requirements. This can be a lengthy process and involve a range of stakeholders. Meetings would take place, end-users would be interviewed, documents examined, existing systems inspected and so on.

The TG’s complex communication difficulties often mean that expressing even basic needs and feelings is a lengthy and fatiguing process. For such individuals it can be difficult, if not impossible, for them to express their requirements of a system being designed for them (Hornof 2009). Added to this was the fact that the system being developed for this study was outside of their experience, with them never having used such a system.

In the absence of customer or end-user requirements, it was deemed more appropriate to identify the ‘perceived needs’ of the TG and then form requirements through a process of:

- Examining and describing the characteristics of the TG and identifying how existing approaches fail to meet the TG’s needs;
- Being mindful of the types of activities that typically developing children might want to engage in;
- Calling upon the expert knowledge of ‘proxy-users’ i.e. professionals who work with the TG including the author (Davies et al. 2010).

A prototyping approach to system development was chosen. This approach is iterative and can be used to produce generations of prototype systems. It is flexible and can be used to hone-in on and refine possible solutions (Rogers et al. 2015).

A flowchart of the systems development method used in this study is shown in Figure 4.1. This approach was used as the basis for designing and implementing both the main robotics-based system and the haptic device.

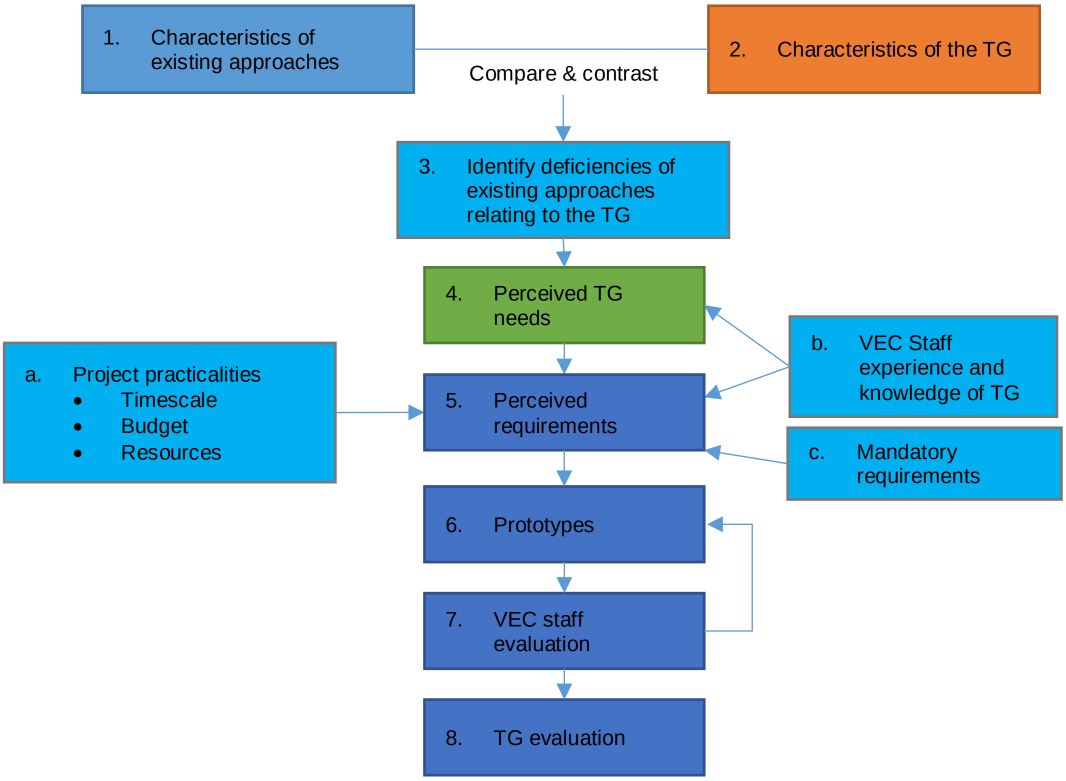


Figure 4.1 Systems development approach

There now follows an explanation of the diagram in Figure 4.1:

1. Identifying the characteristics of existing approaches: These were identified by conducting a state-of-the-art literature review.

2. Identifying the characteristics of the TG: These were derived from the literature, input from professionals at VEC, and the investigator's experience of working as an Assistive Technologist with members of the TG for eleven years prior to the study.

3. Identifying the deficiencies of existing approaches relating to the TG: The common characteristics of existing approaches were compared and contrasted with the characteristics of the TG to identify disparities and conflicts between the two.

4. Perceived TG needs: Using the disparities and conflicts identified in stage 3, the needs of the TG were identified.

5. Perceived TG requirements: These were based upon a combination of: the perceived TG needs (Figure 4.1 - 4); project practicalities (Figure 4.1 - a); VEC staff experience and knowledge of the TG (Figure 4.1 - b); and also mandatory requirements (Figure 4.1 - c) such as health and safety.

6. Prototypes: These were generated based on the perceived requirements. The outputs from this stage can be seen in the Technical Implementation chapter and the Results and Discussion (Staff Participants) chapter.

7. VEC staff evaluation: Prototypes were evaluated by specialist staff ('proxy-users') who worked with the TG in various capacities at VEC. This helped to improve and refine the designs. The results of these evaluations are presented in the Results and Discussion (Staff Participants) chapter.

8. TG evaluation: Members of the TG then used the robotics-based system and the single most appropriate haptic device (as identified by the SPs). This helped to identify how well the aims of the system had been met. The results of these evaluations are presented in the Results and Discussion (Pupil Participants) chapter.

As stated earlier, this approach was iterative and so later stages fed back into earlier stages in order to refine and improve the overall design.

Stages 1 to 5 of Figure 4.1 are described in this chapter, while stages 6, 7 and 8 are covered in the chapters that follow.

4.4 Requirements analysis

Requirements were primarily developed through perceiving the TG's needs, from the research aims and the desirable characteristics for assistive robots for CYP who have motor disabilities (Cook et al. 2010) described earlier.

4.4.1 Perceiving the TG's needs regarding a robotics-based system

This section relates to Figure 4.1, stages 1 – 4, covering the development process for the robotics-based system. This involved identifying the characteristics of existing approaches (stage 1), then the characteristics of the TG (stage 2), comparing these to identify deficiencies (stage 3) and finally deriving the perceived needs of the TG (stage 4). This is illustrated in Figure 4.2.

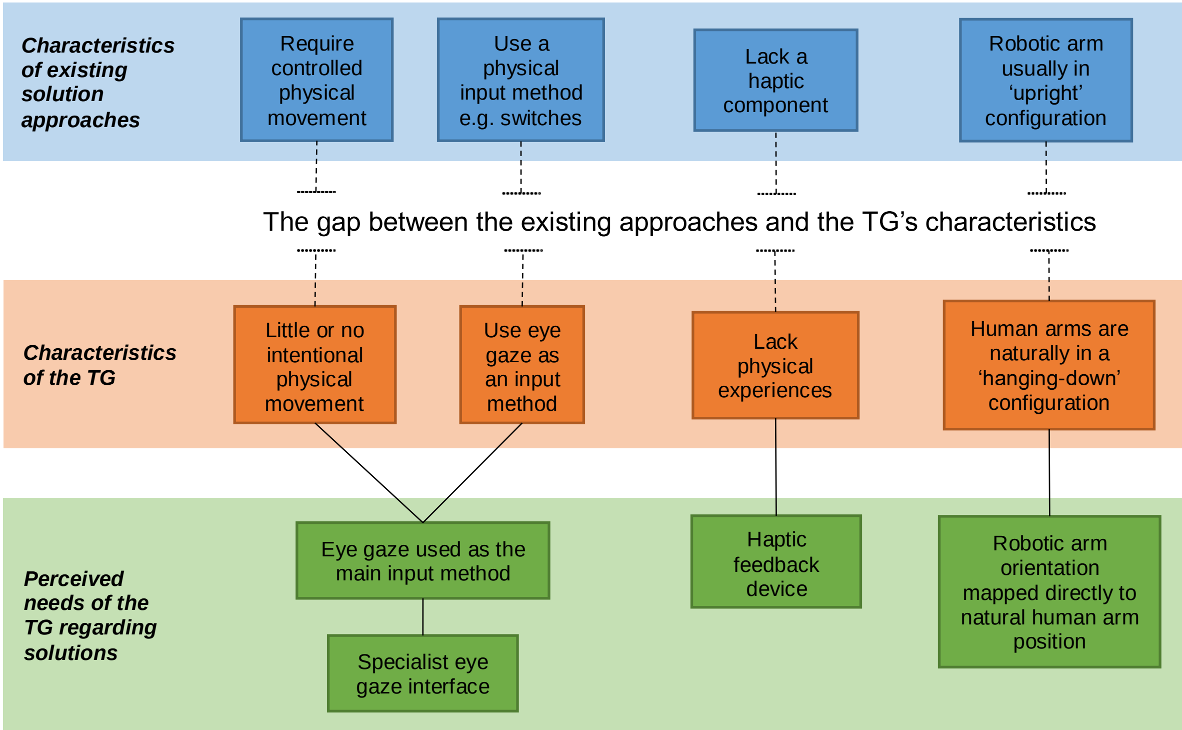


Figure 4.2 Identifying the TG's perceived needs

4.4.2 Robotics-based system requirements

This section relates to Figure 4.1 - stage 5, where the perceived requirements are derived from the perceived needs (stage 4). Based on these perceived TG needs and the desirable robot characteristics in Cook et al. (2010), the following requirements were formed:

- The system should be accessible through a variety of **alternative access methods**, but primarily using **eye gaze** technology as this is often the TG's main input method;
- **Haptic** (and auditory) **feedback** should be generated to provide an experience of, and reinforce the concept of gripping and releasing objects;
- The robotic arm should be **oriented** with the shoulder positioned at the highest point and the elbow and wrist lower, thereby mapping to the relaxed configuration of a human arm and avoiding body dysmorphia issues (Pulay 2015);
- In line with the overall **aims** of this research, the system should provide the TG with the ability to manipulate objects and engage in simple play activities.

At a high level the 'needs-driven' approach outlined previously provides a basic set of requirements. From these high level requirements, a series of more detailed requirements were derived:

- The system should clearly map the **interface** cells to physical actions which are then performed by the robotic arm. The arm should move according to the commands issued;

- The literature indicates that the **positioning** of individual robotic arm joints to achieve a goal can be difficult (Kwee et al. 2002). Instead the end-effector should be positioned in three-dimensional space using simple directional commands such as up, left, forward etc. The system should then translate the new position into a form suitable for the robotic arm.
- The provision of a command sequence (Tsotsos et al. 1998) or "play sentences" (Kwee et al. 1999) feature in order to perform many movements based on the selection of a single cell.
- Allow varying degrees of **autonomy**. As recommended by Cook et al. (2010), in the early stages of use, the robot would have high autonomy, whilst the PP had low. For example the PP selects an interface cell containing a blue cube. The robotic arm moves towards and grips the blue cube, moves it to a container and then releases the cube. In more advanced stages the robot autonomy should decrease, requiring the PP to select several cells consecutively in order to complete a task, for example one cell to pick up a cube, a second to put the cube into a container and so on.
- The precision and coordination needed to accurately position the end-effector and then grip an object could be difficult for the user. The system was required to provide **automation** to assist the PP in this task.

Some system requirements were identified:

- **Safety:** Ensure that no harm comes to anyone as a result of the robot arm.
- **Protection from damage:** The PP may not realise the limits of the robotic arm and so collisions could occur which may strain or damage the arm. The software control layer should prevent this.
- **Reliability:** A spare robotic arm and replacement parts were acquired in case of component failure (Cook et al. 2010).
- **Logging:** To record the performance of the participants.

The perceived needs and requirements, were used to develop a prototype which provided eye gaze control of a robotics-based system in order to perform physical tasks and receive haptic sensations.

4.4.3 Perceiving the TG's needs regarding haptic devices

The same stages were undertaken for the development of the haptic device. This section relates to Figure 4.1, stages 1 – 4, for the haptic device development.

Existing approaches were examined (stage 1), both within the literature and those available commercially. The characteristics of the TG were then identified (stage 2). These were compared to identify deficiencies in existing approaches (stage 3) and finally the perceived needs of the TG were derived (stage 4). This is illustrated in Figure 4.3.

Most existing approaches were found to be based around a ‘glove’ design. There are numerous reasons why existing ‘glove’ based approaches were unsuitable for the TG. These reasons are highlighted in Figure 4.3 and described in greater detail in Table 4.1, which compares the characteristics of existing approaches with the characteristics of the TG.

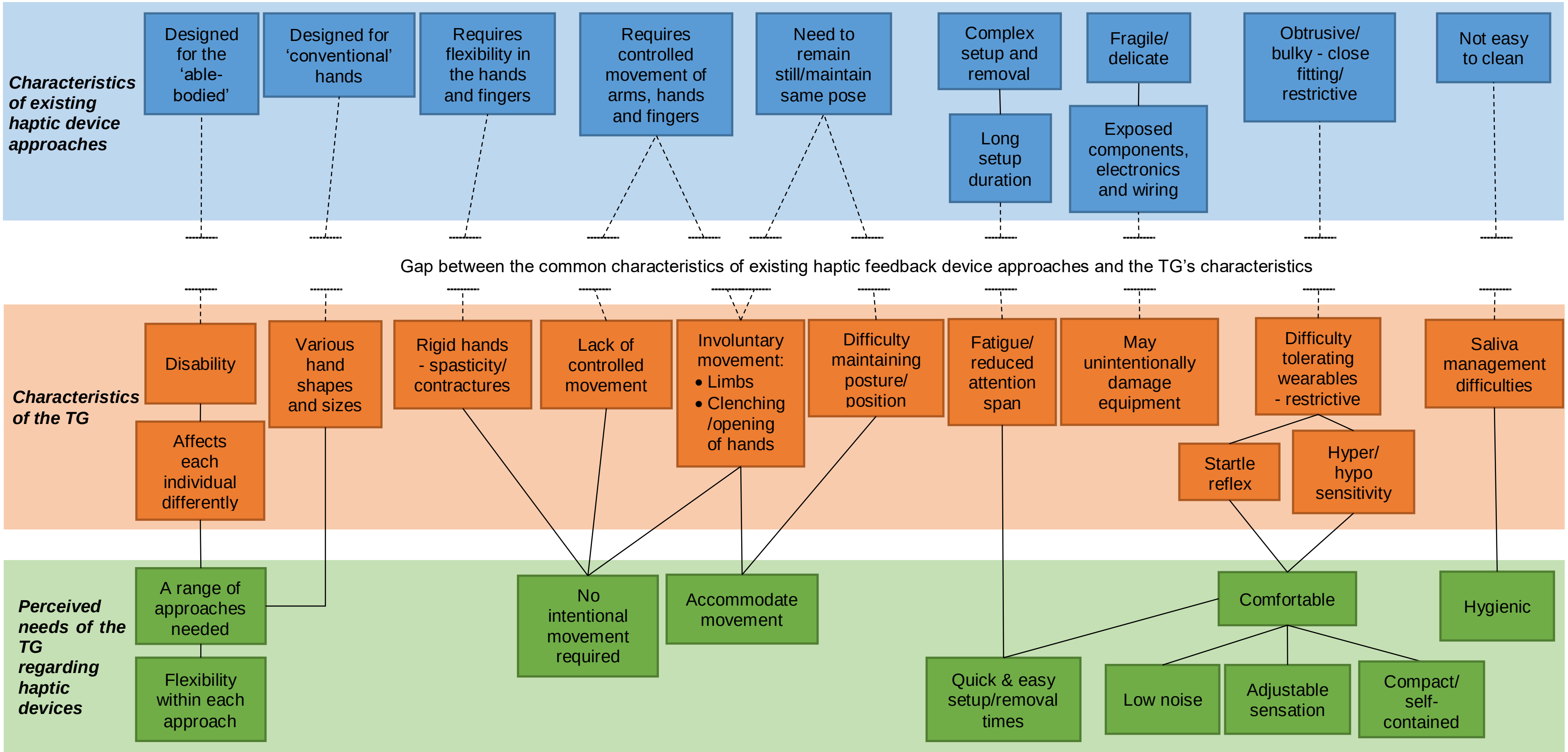


Figure 4.3 A comparison of the common characteristics of existing approaches with those of the TG in order to highlight the needs of the TG regarding haptic devices

Table 4.1 Defining the TG needs of haptic devices through identifying gaps/differences between the characteristics of existing haptic approaches and the TG

Characteristics of existing approaches	Characteristics of the TG	Gaps between TG's needs and the characteristics of existing approaches	TG Needs
Designed for the able-bodied	Disability • Affects each person differently: Each person has different needs	• Most existing approaches are glove based. Putting on a glove would be very difficult if not impossible for those who have tight hands or involuntary movement • The TG have little ability to adapt to technology – the technology needs to adapt to them and their needs	A range of approaches • Different solutions to suit their needs • Flexibility within each approach: Adjustable, adaptable, size, length, width, stretchable.
Designed for 'conventional' hands • frequently designed for adult or 'conventional' hands	Various hand sizes and shapes • TG are young people – smaller hands • Hand shape may be contorted	• The users' needs should dictate the design	
Requires flexibility in the hands and fingers	Rigid hands - Spasticity/Contractures • High tone • May have very tight hands or distorted hand shape	• Flexibility and stability in the hands and fingers is needed to put on gloves	No intentional movement required
Requires controlled movement of arms, hands and fingers	Lack of controlled movement	• When used in virtual environments the wearer usually needs to 'grip' virtual objects or perform gestures	No intentional movement required
Need to remain still/maintain same pose • Often requires the wearer to remain static in specific poses for extended periods of time	Involuntary movement • They may have difficulty achieving and maintaining posture for any longer than a few seconds. • They may strike surfaces or themselves with their hands. Their hands may clench and release uncontrollably. Difficulty maintaining posture/ position	• Involuntary movement would need to be controlled whilst attaching – this can be uncomfortable for the TG • Holding hand in a specific position, holding it up, remaining still	• No intentional movement required • Accommodate movement
Complex setup and removal • Long duration - Protracted configuration/reconfiguration, attachment and removal	Fatigue/reduced attention span • Their condition may limited their ability to concentrate and maintain energy levels.	• TG may not tolerate long attachment/removal times	• Quick and easy setup/removal times • Minimal configuration
Fragile/delicate • Exposed components, electronics and wiring	May unintentionally damage equipment • Those who have involuntary movement may strike their limbs against their surroundings or themselves. • Their hands may involuntary clench or release. • They may lean on things to support themselves.	• May require that the user is careful to ensure that the device does not collide with surfaces or other objects • Involuntary movement could cause potential injury to the TG or damage to the device	Technology needs to be robust
Obtrusive/bulky - Close fitting/restrictive • Intrusive/invasive	Difficulty tolerating wearables – restrictive • Startle reflex - May startle at sudden noises or movement • Hyper/hypo sensitivity - May have 'Tactile defensiveness' whereby sensations are uncomfortable and so touch is avoided.	• Tethered electronics and wiring may restrict movement. • Device is worn - may feel heavy, tight, hot • May be sudden noises, or sensations which may startle the TG or be uncomfortable • May not tolerate wearing things close to the skin	Comfortable • Quick and easy setup/removal times • Low noise • Adjustable sensation level • Compact/self-contained design Ideally the TG should be able to forget that they are wearing the device
Not easy to clean	Saliva management difficulties • Unable to prevent dribbling/drooling	• Electronics may be exposed. Saliva may run into electronics – potential safety and failure issues	Hygienic • Device needs to be hygienic, easy to clean, especially if shared among several users.

4.4.4 Haptic device requirements

This section relates to Figure 4.1, stage 5, which is the generation of the perceived TG requirements for the haptic device. The TG's perceived needs formed the basis of the haptic device requirements. An additional range of requirements arose based on the need to ensure the health and safety of the TG. These are identified in Table 4.2.

Table 4.2 Haptic requirements/design considerations

Existing approach	**TG**	**Requirements**	**Technical challenges**
May not attach securely	Involuntary movement	• Needs to be firmly attached to prevent detachment during TG movement	• Providing ways to attach the device to the TG comfortably • Providing a design which moves with them
Comfort may be of low priority	Comfort will help the TG to tolerate the device and prevent rubbing/pressure discomfort or injury	• Comfortable • Compact	• Ergonomically designed – 3D printed • Sourcing small components - Miniaturisation • Controller board, wireless, battery, and motor all within one small unit • Bespoke design
Durability may be low priority	Durability is important to prevent injury resulting from a broken device	• Rugged, durable	• Sourcing materials to produce a protective casing • Can withstand being shaken, struck, crushed and saliva
Mains/battery powered	Unable to remove the device themselves if malfunctions occur May take them some time to alert others of a problem Changing batteries/devices during the session would be disruptive for the TG	• Safe components • Battery stamina must last throughout the session as a minimum	• Identifying safe battery technologies/remote power sources (safety issues with volatile battery technology – Lithium ion rechargeable) • Battery stamina – minimise power consumption
Exposed components Often large with exoskeleton attachments, or extensive external wiring and electronics	Could get tangled in wires, injury from components	• Wireless and independently powered • Self-contained • No sharp edges	• Miniaturisation
Prototypes are often unreliable	Essential that the device works reliably to establish cause and effect	• Reliable	• Ensuring good design. Exhaustive testing
Health and Safety	Avoid injury of any kind	• Soft • Non-allergenic	• Investigate suitable materials

4.4.5 *Potential haptic approaches and suitability for the TG*

The suitability of a particular haptic feedback device very much depends upon the characteristics and needs of the user. Some devices may have inherent design characteristics which mean that they are appropriate for a wider range of users.

Figure 4.4 shows a decision tree for the selection of a potential haptic device based on an individual's physical characteristics.

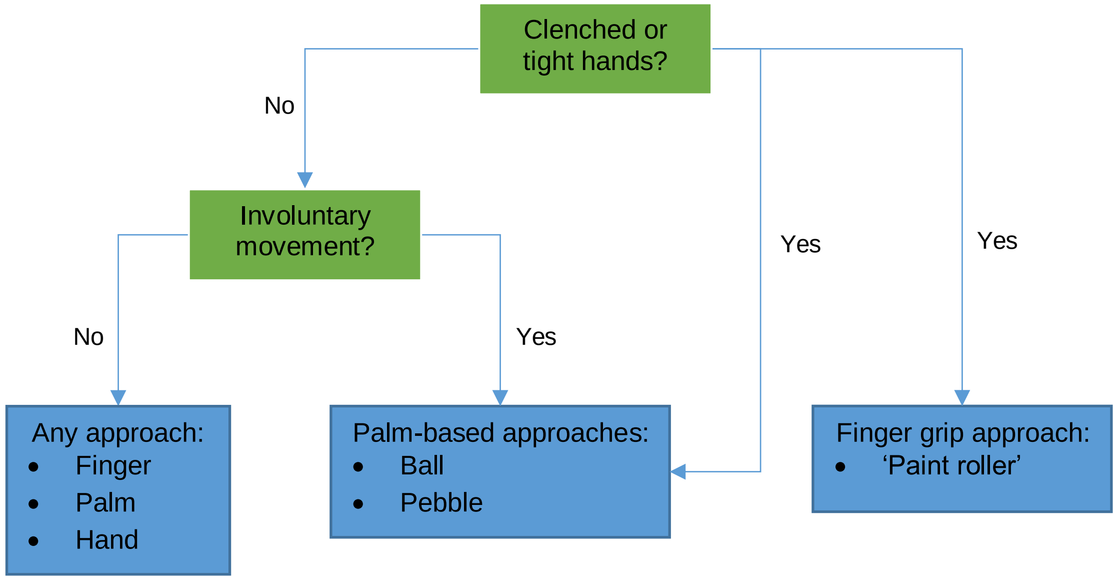


Figure 4.4 Haptic feedback device selection approach

Whittington et al. (2019) developed an app which can suggest suitable AT based on an individual's range of movement (ROM). The difference in the current study is that the selection of a haptic device was not based on the TG's ROM, but on other characteristics such as ease of attachment, and comfort, since the current TG have little or no controllable ROM.

Table 4.3 gives examples of the suitability of different approaches for different users. The colour coding used indicates some of the positive aspects (green) and the negative aspects (red) of the various approaches.

Table 4.3 Suitability of haptic approaches

	Setup and removal time	Movement characteristics of the wearer	Spasticity level	Durability	Comfort level	Level of intrusion/ Intrusion rating	Disadvantages
Glove	Long/impossible	None -> little	None -> little	Low	Low	High	Many
Finger attached	Medium	None -> little	None -> little	Low	Low	High	Wiring
Grip	Medium	Little -> medium	Medium -> high	Medium	Medium	Low	No palm sensation
Hand	Fast	Medium	None -> little	High	Medium	Medium	Donning/doffing
Palm	Fast	Moderate -> severe	None -> little	High	Medium ->high	Low	Limited finger sensations
Combination of palm and finger	Medium	Little -> medium	None -> little	Medium	Medium	Medium	Many, especially wiring

4.5 End of chapter summary

A modified version of the HAAT model (Cook and Polgar 2014) adapted for assistive robots by Cook et al. (2010) was used to shape the requirements, design and development of both the technology and the tasks used in this study.

Establishing the requirements of a robotics based system and a haptic feedback device suitable for the TG was achieved through a process of examining current solutions and identifying why they would not meet the needs of the TG. Using the gaps identified a number of requirements were identified. This process informed the design and technical implementation within this study which is the subject of the next chapter.

Chapter 5 Technical Implementation

5.1 Introduction

This chapter describes the technical elements of this research i.e. the robotics-based system including the haptic device. The robotics-based system was used by the PPs to complete a range of tasks during the intervention stage of the study. The system is comprised of a number of different elements and involves both software and hardware, inputs and outputs.

An example configuration of the system, for the 'Scenarios' task stage, is shown in Figure 5.1.

Figure 5.1 The robotics-based system

The system architecture and operation are described in the next section.

5.2 System operation

Figure 5.2 provides an overview of the main components and control mechanisms of the robotics-based system. The robotic arm is manoeuvred using an interface which can be controlled using eye gaze - the access method of the PPs. The PP (1) selects an interface cell by briefly 'dwelling' their gaze upon it (2). This action triggers a command which is sent to the software control layer (3). The software control layer then forwards this command to the robotic arm (4). Haptic feedback is sent to the user's hand whenever the robotic arm is gripping an object and this is provided by a bespoke hand-based haptic device (5).

Note: Before selecting a command cell the PP needed to activate/'un-rest' eye gaze operation each time by dwelling on the  cell. This was to avoid the 'Midas touch' (Jacob 1990) or 'unwanted selections' (Encarnação et al. 2016).

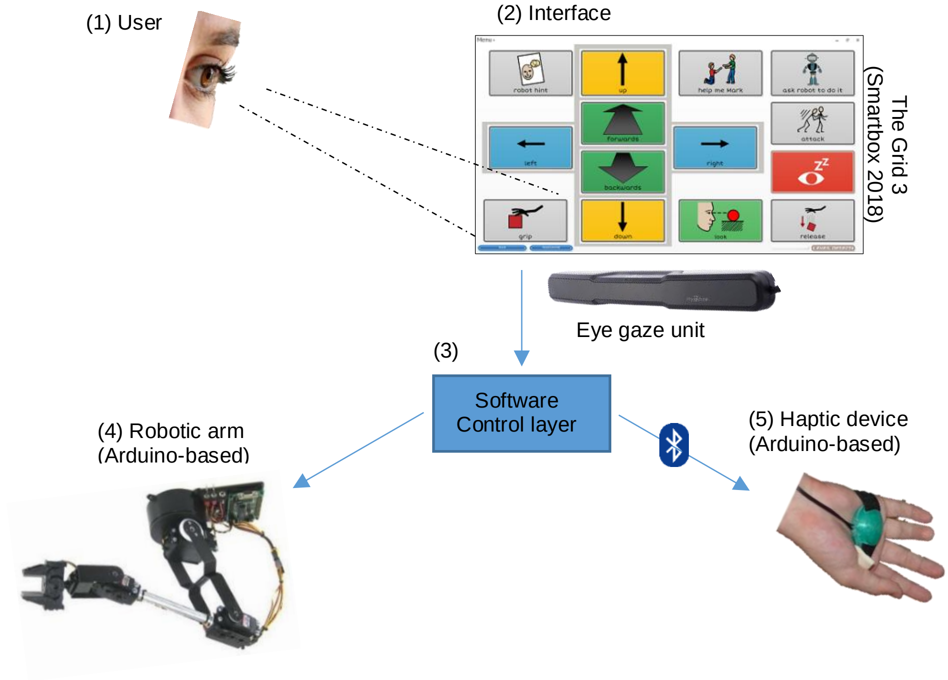


Figure 5.2 The robotics-based system flow of operation

5.3 System architecture

The robotics-based system is comprised of many hardware and software parts (see Figure 5.2). For the purposes of explanation these have been divided into three areas (see Figure 5.3): (1) The user area; (2) The Area of operation (AOO); and (3) The system control area.

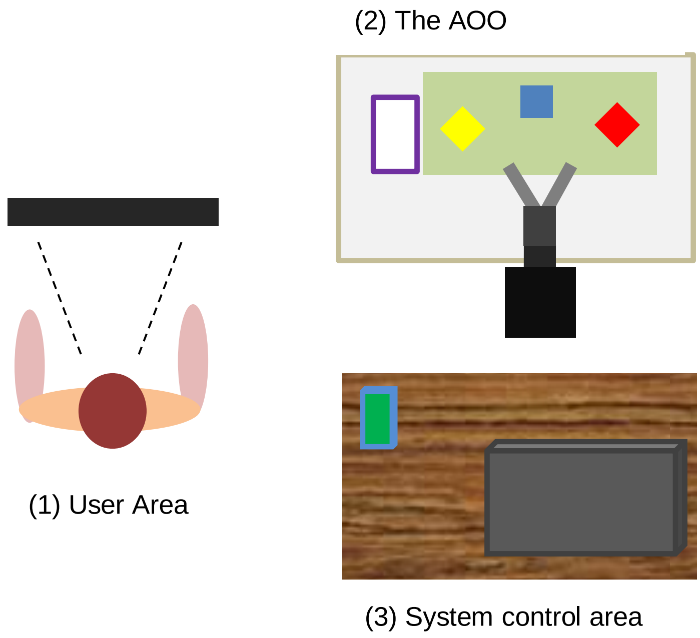


Figure 5.3 The three areas of the robotics-based system

5.3.1 *(Area 1) The user area*

The user area is where the PP controlled the robotic system from during the intervention tasks.

The user area contained the GUI (Graphical User Interface) which was presented on a display, with an eye gaze device attached beneath the display. The display and eye gaze device were mounted on a fully adjustable floor stand.

The display presents one of two possible views, depending upon the current context of operation (see Figure 5.4). The GUI is displayed when the user is instructing the system (see Figure 5.4 - a). When an instruction is being carried out a live video feed is shown on the display and the UI is not available (see Figure 5.4 - b). This video feed comes from a webcam positioned above the robotic arm. The purpose of showing the live video feed is twofold: 1) to display an alternative perspective view to the user; 2) to prevent accidental user interface selections whilst a command is being carried out.

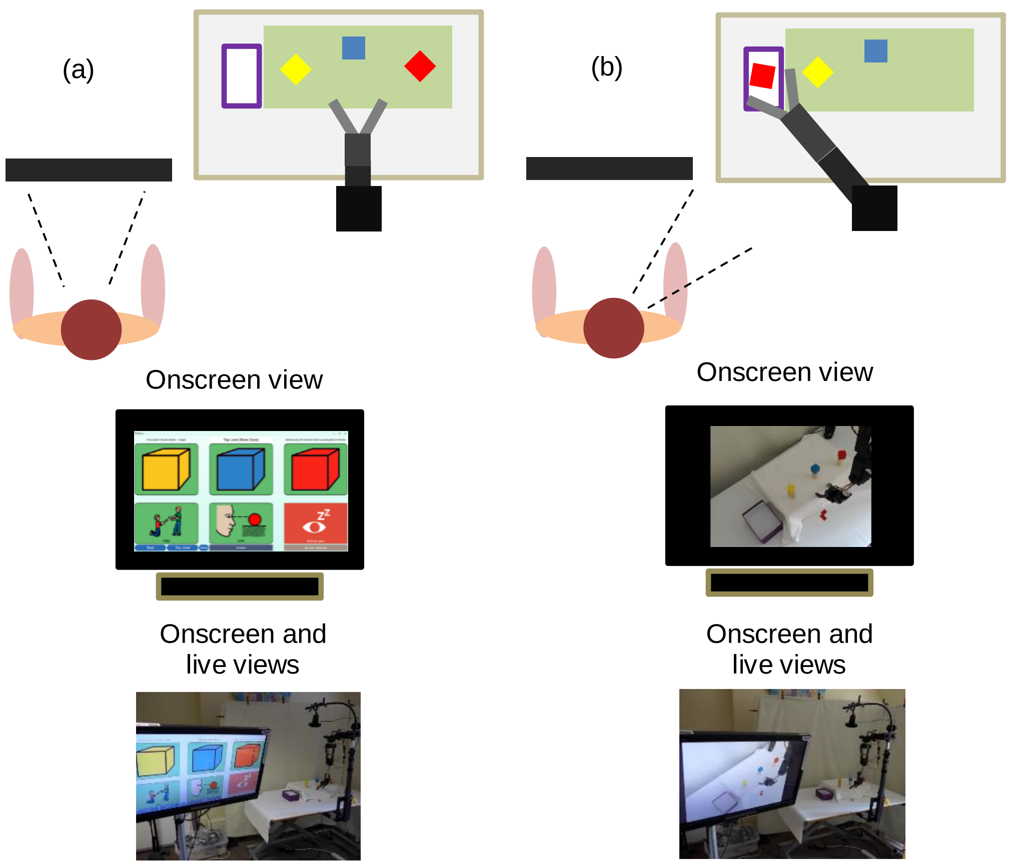


Figure 5.4 The UI and onscreen and live scene views (NOTE: The photographs in (b) are indicative only – they do not show the actual robotic arm's movement)

The PPs were able to view the scene from two different perspectives: from an elevated position via the video feed and also from their position by looking diagonally to their right (see Figure 5.4).

The purpose of providing both a 'live' view and an onscreen view was to assist the PP with depth perception, as they were not able to reposition themselves to view the scene from different angles. This also provided an alternative approach to the user having to look at the screen to issue a command and then look at the live scene to see the effect (Encarnação et al. 2016).

The user area was separated from the AOO for safety reasons i.e. to keep the user beyond the reach of the robotic arm.

5.3.2 (Area 2) The area of operation (AOO) / Scene area

The Area of Operation (AOO) is the space in which the robotic arm operates and where the scene and tasks are set. Figure 5.5 shows two examples of the AOO during the tasks 'Directions' and 'Scenarios'.

Figure 5.5 The AOO – two example configurations

5.3.3 (Area 3) The system control area

The system control area contains the central controlling computer, the haptic control unit and the researcher's equipment (camera and tripod for recording, and paperwork).

5.4 Equipment

The robotic system is comprised of a range of equipment, as shown in Figure 5.3. This equipment will now be categorised by each of the three areas described above i.e. User area, AOO and System control area:

5.4.1 Area 1: User hardware area

(1) Touch screen display
(2) Eye gaze unit
(3) Fully adjustable floor stand
(4) Hand-based haptic device

5.4.2 *Area 2: AOO hardware*

(1) Height adjustable table with sound-absorbing covering (to avoid the PPs becoming startled when hard objects fall upon the table during the tasks)
(2) Robotic arm
(3) Robotic arm mounting
(4) Webcam / Video camera: this was affixed to the robotic arm mounting in an elevated position
(5) Stereo loudspeakers
(6) Scene items: The task setting e.g. pirate ship, and additional materials such as building blocks
(7) Raised area ('Cubes' and 'Scenarios' only): to make the scene more easily visible and to assist the gripping process
(8) Screening: to reduce distractions and to make the scene the focal point

5.4.3 *Area 3: System control area hardware*

(1) Haptic control unit
(2) Central controlling computer
(3) Researcher's equipment: A camera and tripod for recording sessions

The specific equipment configuration varied for each of the different task stages. All had common elements, but the 'Cubes' and 'Scenarios' stages included the following equipment:

(1) Palm / Hand-based haptic feedback device and controller
(2) A raised area (or platform) on the centre of the table

The 'Directions' stage did not use the two items above.

5.5 The haptic feedback device

Tactile feedback was provided by a purpose-built palm-based haptic device. The haptic device consisted of two parts: 1. The palm-based device (see Figure 5.6); and 2. The haptic control unit (see Figure 5.7). The two were connected by a socket on the haptic control unit.

Figure 5.6 The palm-based haptic feedback device attached to PP2's hand

Figure 5.7 A haptic control unit

5.5.1 The hand-based haptic feedback component / device

The palm-based haptic device consisted of an elliptical shaped 3D printed casing containing a small vibration motor (see Figure 5.8).

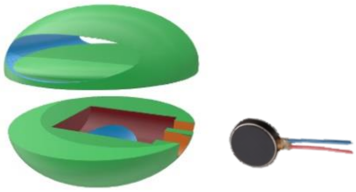


Figure 5.8 Palm-based haptic device - CAD design with vibration motor

The casing for the palm-based haptic feedback device was designed using CAD software and fabricated using a 3D printer. It was constructed from PLA filament material which is considered to be a non-toxic material. The device was secured to the hand using an elasticated hook and loop strap (see Figure 5.9).

Figure 5.9 Palm-based haptic feedback device

5.5.2 The haptic control unit

The purpose of the haptic control unit (see Figure 5.7) was to safely provide power to the vibration motor within the palm-based haptic device, and to control the spin / rotation speed, and spin up and spin down durations.

The control unit receives power from two AAA batteries and connects to the palm-based haptic device using just one cable. The connection between the haptic controller and the controlling computer is wireless (Bluetooth).

5.6 Hardware connections and specifications

5.6.1 *Controlling computer connections*

The hub of the robotic system was the controlling computer which had many connections to the other components of the system. These are shown in Table 5.1 and Figure 5.10.

Table 5.1 Connections to the controlling computer

Type of connection	Peripheral
USB	Eye gaze unit Robotic arm Webcam Touchscreen controller
Audio-visual	HDMI (to touch screen display) Sound (to speakers)
Wireless	Bluetooth connection to the haptic control unit(s)

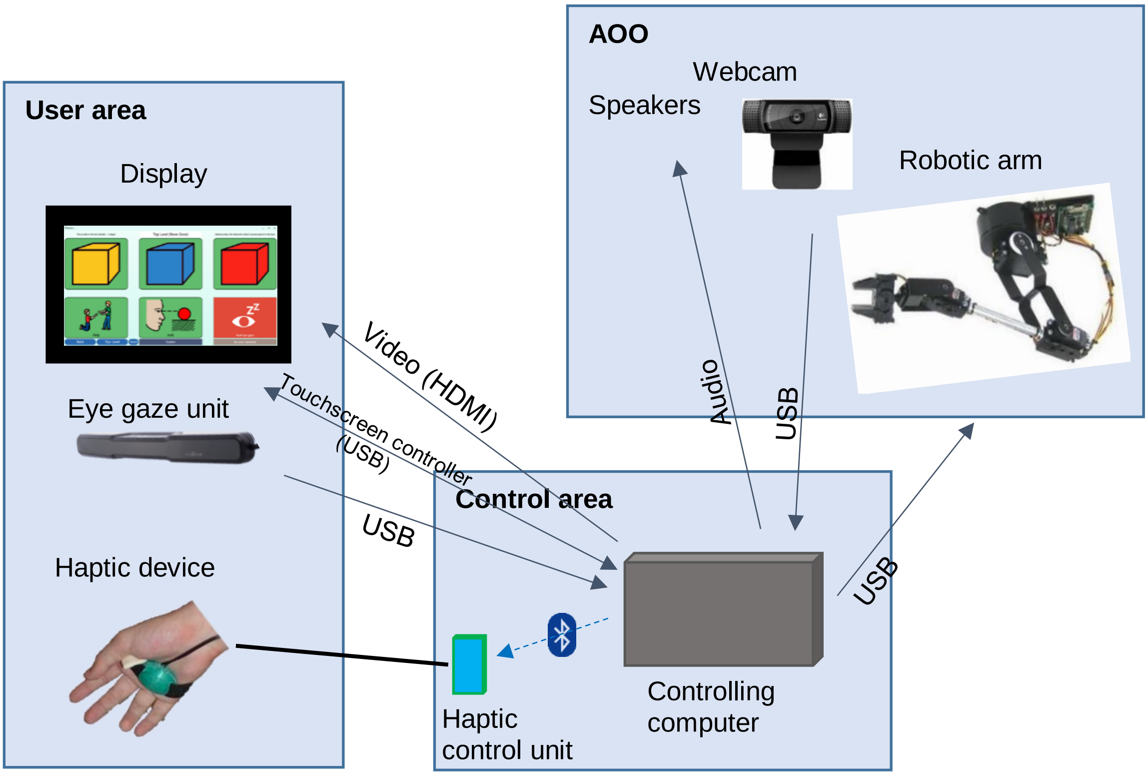


Figure 5.10 Data connections (physical and wireless) and the direction of communication (by area)

5.6.2 *Robotic arm*

The robotic arm used within this study was a LynxMotion AL5D with Botboarduino robot controller (RobotShop inc. 2016). This arm uses electrically powered servos and has five Degrees of Freedom (DOF).

5.6.2.1 Robotic arm movement

The AL5D robotic arm can move in the combinations shown in Table 5.2.

Table 5.2 Robotic arm joint movements

Joint	Movements
Shoulder	Up / down Rotate clockwise / anti-clockwise
Elbow	Up / down
Wrist	Up / down
Gripper	Grip (Close) / Release (Open)

This range of movement enables the end-effector to:

(1) Move up and down
(2) Rotate clockwise and anti-clockwise / pivot left or right
(3) Move forwards and backwards
(4) Grip and release objects
(5) Perform combinations of movements 1 - 4

5.6.2.2 Adaptations made to the robotic arm

For the purposes of this research, several adaptations were made to the robotic arm:

(1) The robotic arm needed to be mounted upside-down. This required upgrades to the robotic arm base and shoulder components and also modifications to the load bearing of the arm.
(2) A wider gripper aperture was required and so a custom gripper was added to the existing gripper to widen the grip and to extend the jaws (see Figure 5.11).

Figure 5.11 The robotic arm gripper / jaws with custom extensions

(3) All connecting servo cables were upgraded to versions with tighter connectors to prevent disconnections.

A wired connection was used to connect the controlling computer to the robotic arm (using a serial / COM port). The robotic arm could also be used wirelessly, but a wired connection was chosen for improved reliability (and safety).

5.6.2.3 Robotic arm mounting

A custom-made robotic arm table mounting was designed and created by the rehabilitation engineer at VEC. This was a permanent static mounting. Later a portable mounting was designed using commercially available photography mounting equipment.

5.6.2.4 Limitations of the robotic system

The robotic system did not utilise any Computer Vision techniques for locating objects in the scene. Instead the system operated based on preprogramed x, y and z coordinates for the positions of objects in the scene relative to the position of the gripper.

Haptic device activation functioned on a similar basis. The gripper did not contain any sensors and so was set to grip when arriving at specific locations, such as that occupied by a cube or character. Force Sensing Resistors were trialled but found to be unreliable.

5.7 Software

The system utilised a suite of software. Some of this software is commercially available or open source and some was created specifically for this study (see Figure 5.12). The software is divided into three groups and can be summarised as follows:

(1) Control software
    (a) GUI (Graphical User Interface)
    (b) Haptic control
    (c) Robot control
    (d) Tasks
(2) Haptic device software
(3) Robotic arm software

The hub of the system is a central controlling computer (Figure 5.12 – (1)) which contained the control software. The control software includes: software to interface with the user (Figure 5.12 – (1) (a) (i) and (ii)) the haptic feedback device (2); and the robotic arm (3). The haptic feedback device and robotic arm also contain embedded software which facilitates communication with the central controlling computer and control of the particular device.

Some of the software running on the controlling computer is specific to certain tasks i.e. during ‘Cubes’, the Grid 3 interacts with the robotic arm and haptic controller using relatively simple bridging software, whereas ‘Scenarios’ requires much more sophisticated functions.

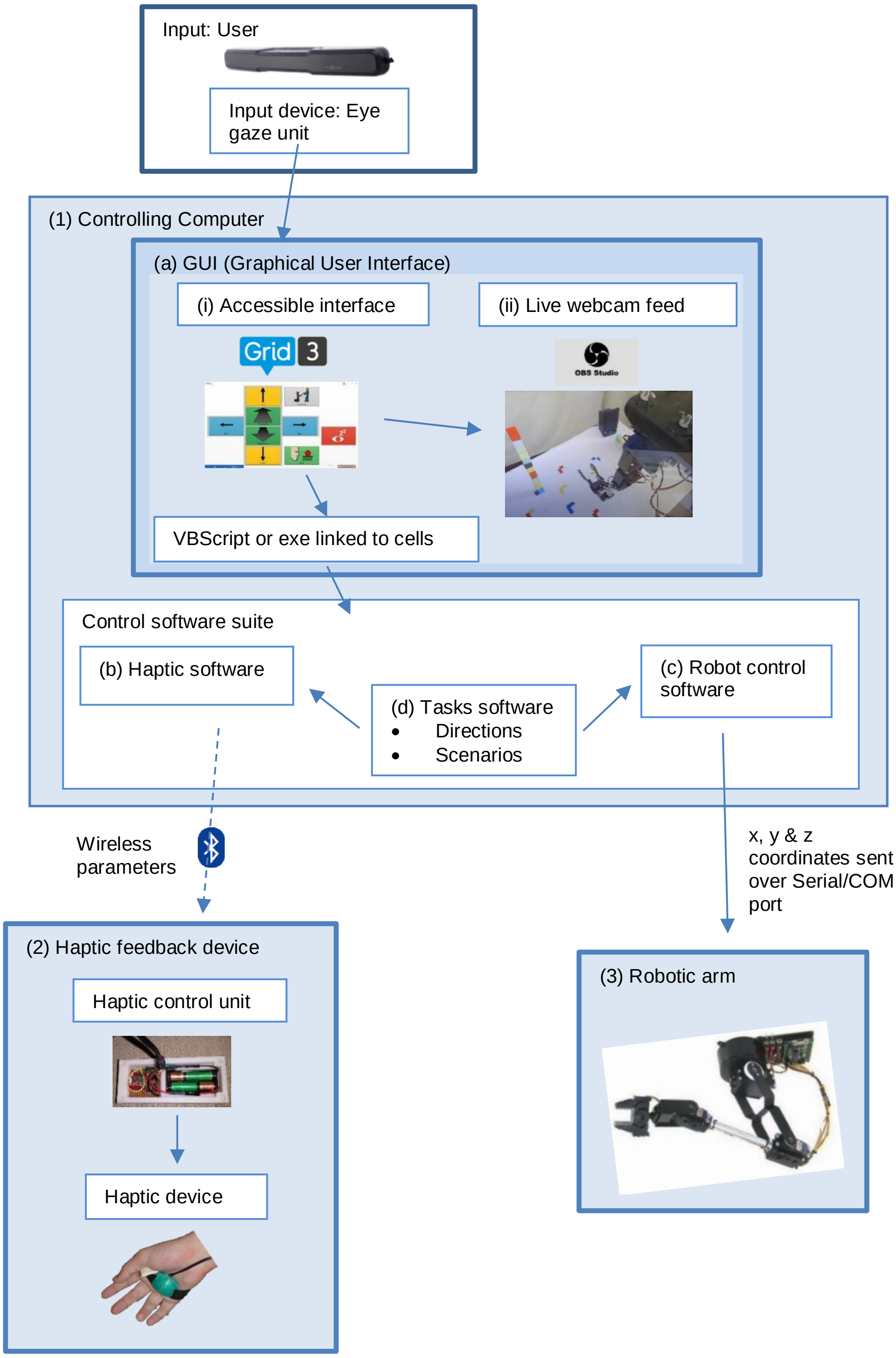


Figure 5.12 Robotic system hardware and software schematic

5.8 Software Group 1: Controlling computer software

Summary: The controlling computer contained a suite of software responsible for the interface with the user, robotic arm and haptic feedback control. These will be explained in more detail in the coming sections.

5.8.1 The GUI (Graphical User Interface) (Figure 5.12 - a)

The GUI was provided using Grid 3 and OBS studio software:

(1) Grid 3

Grid 3 (Smartbox Assistive Technology Limited 2016) was used as an accessible user interface wrapper for the PP to send commands to the robotic system.

The Grid 3 software provided a range of alternative access methods, including eye gaze. Grid 3 includes speech synthesis and symbol support to augment understanding. It also provides the ability to run executable files and vbScript files and so can be used as a control point for other software, as was the case in the current study.

(2) OBS studio

OBS Studio (Jim 2019) was used to capture the video feed from the webcam. Once the PP had instructed Grid 3 to issue a command to the robotic system, OBS studio would present the live feed from the webcam on the display.

5.8.2 Haptic software (Figure 5.12 - b)

This software formed a bridge between Grid 3 and the haptic technology, relaying instructions from the user interface to the haptic control unit and then to the haptic device. This software communicated with the haptic control unit wirelessly using Bluetooth.

5.8.3 Robot control software (Figure 5.12 - c)

This software formed a bridge between Grid 3 and the robotic arm, passing instructions from the user interface to the robotic arm.

5.8.4 Tasks software (Figure 5.12 - d)

The tasks software was used only in the 'Directions' and 'Scenarios' stages. This software provided more sophisticated control of the robotic arm. The duties performed will be discussed later in the relevant sections.

5.9 Basic flow of operation between the interface, robotic arm and haptic control unit

The basic flow of operation between Grid 3 and the robotic and haptic components would typically follow one of two paths:

(1) Running an executable file; or
(2) Running a vbScript file which creates a .txt file
    (a) The .txt file contents are picked up by a running program
    (b) The command is sent to the relevant device by the running program

The actual operation path for each of the task groups will now be discussed (see Figure 5.13, Figure 5.14 and Figure 5.15).

'Cubes': Grid 3 sends commands to the robotic arm using a simple executable file, and to the haptic device via a vbScript file (generating a .txt file):

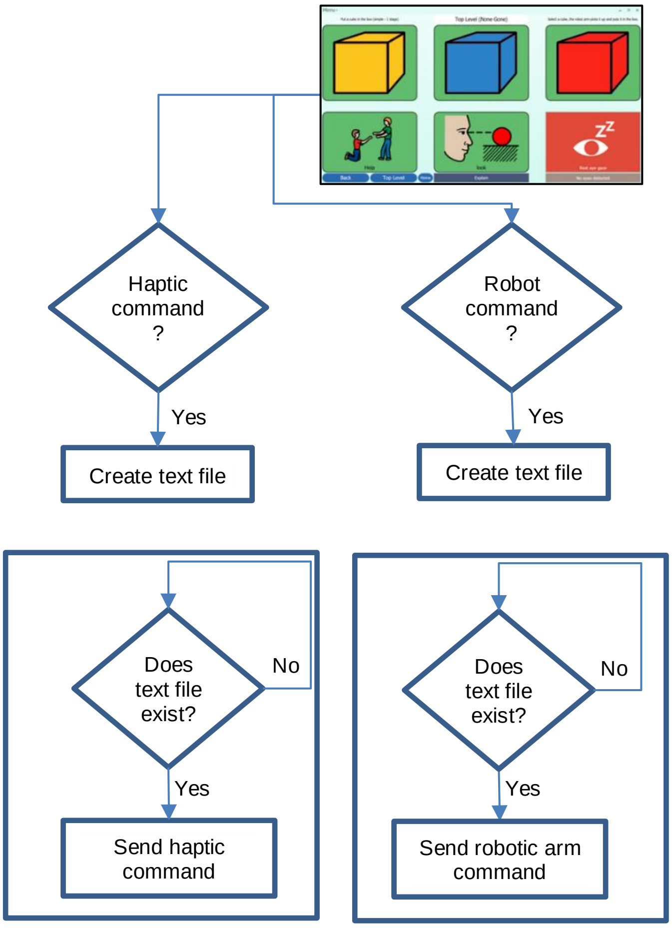


Figure 5.13 'Cubes' flow chart

'Directions': Grid 3 commands were sent to the robotic arm via a vbScript file (generating a .txt file)

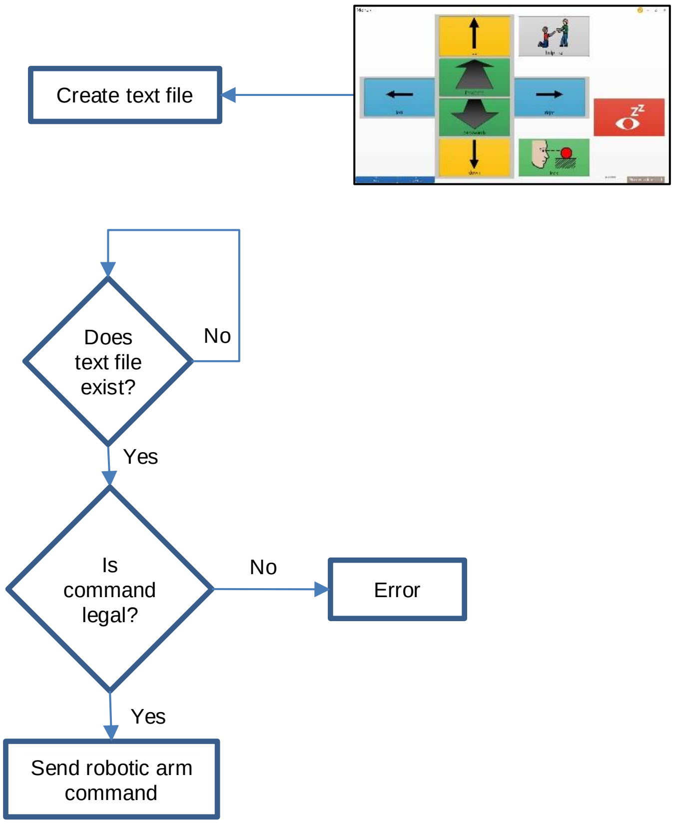


Figure 5.14 'Directions' flow chart

‘Scenarios’: Grid 3 commands were sent to the robotic arm and the haptic device via a vbScript file (generating a .txt file)

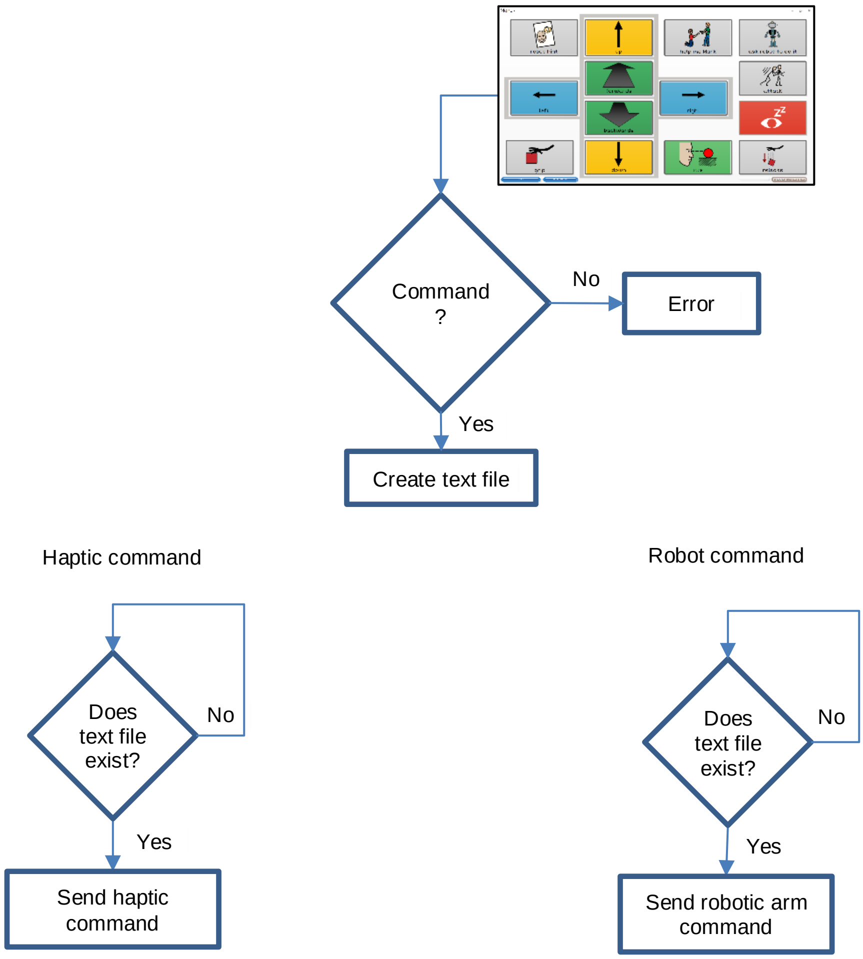


Figure 5.15 ‘Scenarios’ flow chart

5.10 Software Group 2: Haptic control unit software (positioned between the controlling computer and the haptic device)

Summary: The haptic control unit contained software which received commands from the controlling computer and then activated or deactivated the haptic device accordingly.

Communication between the controlling computer and the haptic control unit was wireless (Bluetooth). Both the controlling computer and the haptic control unit contained software which enabled communication between the two:

(1) The controlling computer haptic software was responsible for establishing and maintaining the connection between the controlling computer and the haptic control unit and for issuing commands to the haptic control unit.

(2) The haptic control unit had two functions: (1) to supply power to the haptic device; and (2) communication and control. The haptic control unit software accepted and carried out the commands sent from the controlling computer, i.e. it provided power to the palm-based haptic device to make the motor spin / rotate. It also controlled the spin up and down behaviours and durations, as well the constant spin speed / rotation of the motor. The motor could be set to spin up or down abruptly or gradually. The gradual approach was used within this study as it appeared to be less startling and so more comfortable for the wearer.

5.11 Software Group 3: Robotic arm software (AL5D software on the Botboarduino / Arduino)

Summary: The robotic arm contained software which received commands from the controlling computer and translated these into individual joint angles and then relayed these to the robotic arm's servos.

The software running on the robotic arm's controller board (Botboarduino) was designed to receive and translate the x, y and z coordinates sent from the controlling computer, into individual joint angles so that the end effector, or gripper, reached the specified x, y and z point.

Inverse kinematics (trigonometry-based) is used to calculate these angles. The user needs only to direct the gripper to a desired destination. The software running on the Botboarduino calculated the various joint positions for the gripper to reach the desired 3D point in space.

Encarnação et al. (2016) found that participants often had difficulties understanding the concepts of rotation and frame of reference, particularly in directing robots which were driving forwards towards them. In the current study these issues were avoided by ensuring that the robotic arm was always within the PP's frame of reference i.e. facing in the same direction as the PP. Also, rather than the arm's gripper arcing left and right, up and down, it maintained a movement path along horizontal and vertical planes (see Figure 5.16 (right)). This helped to avoid the overshooting of objects because of rotation issues, and the confusion of a forwards movement appearing to be left or right at the arm's rotation extremities.

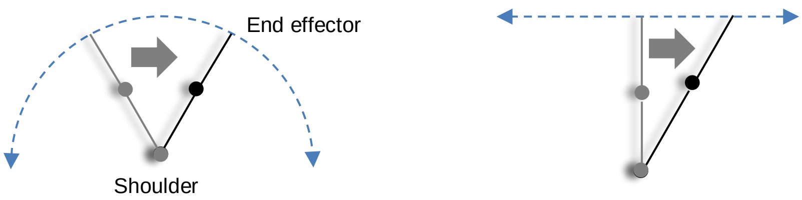


Figure 5.16 As seen from above, the normal arcing path of a robotic arm (left) and the modified linear path used in the current study (right)

5.12 Task stages

The tasks were divided into three distinct groups: 'Cubes', 'Directions' and 'Scenarios'. The following sections describe the technical implementation of each of these stages.

5.13 'Cubes'

The 'Cubes' task group involved the researcher asking the PP to perform a specific task such as 'put the red cube in the box'. The PP was then expected to complete the task by instructing the robotic system. These tasks also involved the haptic device described earlier. Figure 5.17 shows the equipment configuration for 'Cubes'.

Figure 5.17 Equipment configuration for 'Cubes'

To complete the tasks in the 'Cubes' stage, the PP would select an interface cell (see Figure 5.18) containing the symbol of a cube that they thought would complete the task.

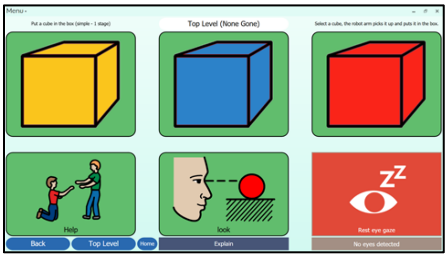


Figure 5.18 The graphical user interface for 'Cubes'

Control would then be handed over to the robotic system which would carry out all of the required movements with no further intervention required from the user. If the chosen cube was still available i.e. it was not already in the box, the robotic arm would grip the cube and the PP would receive a haptic sensation from the palm-based haptic device for the duration of the gripping stage. If the cube was no longer available, the movements would still be carried out, but there would be no haptic sensation.

Point of note: The robotic arm was not configured to move to its destination by the most direct route i.e. along a single vector (although this was possible). Instead, it was programmed to move using a series of left (anti-clockwise), right (clockwise), up, down, forwards and backwards movements. This was to explicitly show the PPs the combination of movements, with the intention that the PPs could observe and learn how the arm could be moved between points using the six direction commands.

Example: Task: Put the red cube in the box

(1) The PP selects the cell from the interface (see Figure 5.18) which they believe will complete the task
(2) The robotic arm then carries out all of the individual movements required to manoeuvre the selected cube from its plinth into the box. The haptic device activates during the gripping stage.

5.13.1 Description of how 'Cubes' was implemented

The interface software (Grid 3) cells each had a series of commands assigned against them. When a cell was selected these commands were triggered in sequence with pauses between them to allow time for each command to be executed. Some of these commands controlled the robotic arm and others the haptic device.

During the 'cubes' stage, the robotic system had high levels of autonomy and the user low levels of autonomy i.e. the robotic system performed the individual movements autonomously, the user only had to select a single cell.

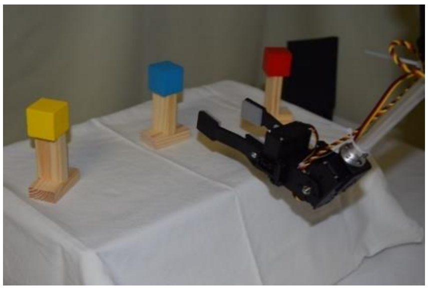


Figure 5.19 'Cubes' close-up view of the scene

5.14 'Directions'

The tasks in the 'Directions' group involved the user manoeuvring the robotic arm to demolish block-based structures positioned within the AOO. This stage did not involve haptic feedback as the tasks did not involve gripping.

The user had control over the robotic arm's individual movements (see Figure 5.20 for the full range of movements available). Only operational limits were imposed during this stage. The limits were there to protect the mechanisms of the robotic arm, preventing collisions with other parts of the robotic arm and the mounting system. The user would instruct the robotic arm's end effector to move one unit of distance with each command.

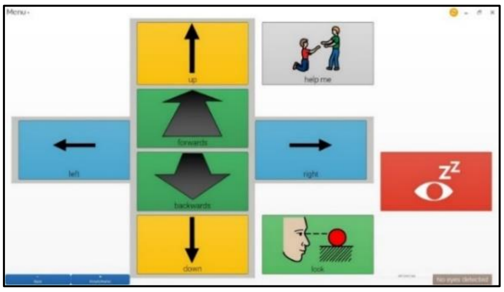


Figure 5.20 Graphical user interface for 'Directions' (all operations)

5.14.1 Description of how 'Directions' was implemented

Once a UI cell had been selected by the PP, the associated command would be sent to the controlling computer software. This software would evaluate whether the move was legal and, if so, instruct the robotic arm to carry out the move.

The duties performed by the controlling computer software relating specifically to the 'Directions' tasks were:

(1) The initial starting position of the robotic arm was set according to the requirements of the specific task. For example, if the task was to move the robotic arm 'down' to demolish a low structure, the robotic arm would start from a higher position;
(2) Imposing operational limits;
(3) Providing recorded speech feedback;
(4) Determining units of movement.

5.15 'Scenarios'

The 'Scenarios' group involved rudimentary robot-assisted play in which the PP first created a story, and then used the robotic system to enact the story. This task contained haptic feedback during the 'gripping' stages.

A single play scenario was chosen for this study – that of two characters (a pirate and a giant crab) battling to take control of a pirate ship.

The PP was first asked to create a story using the characters and the pirate ship. The user would first choose a 'winning' and a 'losing' character from the pirate and the crab, and then decide where to position these characters from three possible locations on the pirate ship: bow, stern or crow's nest (see Figure 5.21).

Figure 5.21 Setting up the story for 'Scenarios'

The researcher would then set up the physical scene (see example in Figure 5.22) and also configure the story settings within the software (see Figure 5.23). The PP would then use the robotic arm to first grip the winning character, and then use the winning character to knock the losing character from the pirate ship. The GUI with the controls is shown in Figure 5.24. As with 'Directions', the PP could move the gripper one unit of distance, in a single direction at a time. Operational limits and collision detection were imposed.

Figure 5.22 The pirate ship with the characters in position

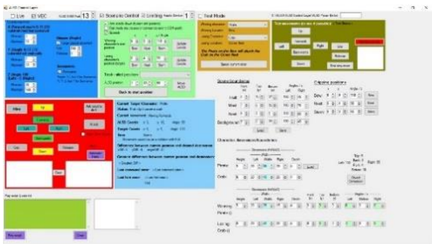


Figure 5.23 Controlling computer software interface

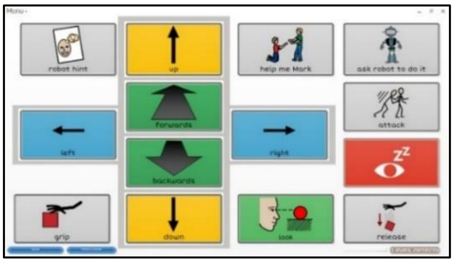


Figure 5.24 The 'Scenarios' interface

The robotic system was able to assist with difficult manipulation operations, such as character gripping and 'attacking'. The system was also able to provide suggestions, or 'hints', on how to complete the story. These features will be discussed further on in this chapter.

5.15.1 The main stages of the 'Scenarios' story enactment

The main stages required for a PP to complete the story enactment were as follows:

(1) Move the gripper towards the winning character
(2) Grip the winning character (with assistance from the system)
(3) Move the winning character towards the losing character
(4) Attack the losing character with the gripped winning character (with assistance from the system)
(5) Put the winning character in the losing character's location
(6) Return the robotic arm to the start position

The equipment and the system mechanisms will now be described.

5.15.2 The story setting (pirate ship)

The pirate ship provided a setting for the story and the characters (see Figure 5.25). It contained three locations where the characters could be positioned (one character per location).

Figure 5.25 The pirate ship

To prevent the robotic arm from colliding with the scene, basic collision detection algorithms were included. The shape of the setting, in this case the pirate ship, is internally represented in the controlling software using a set of cuboids (see Figure 5.26).

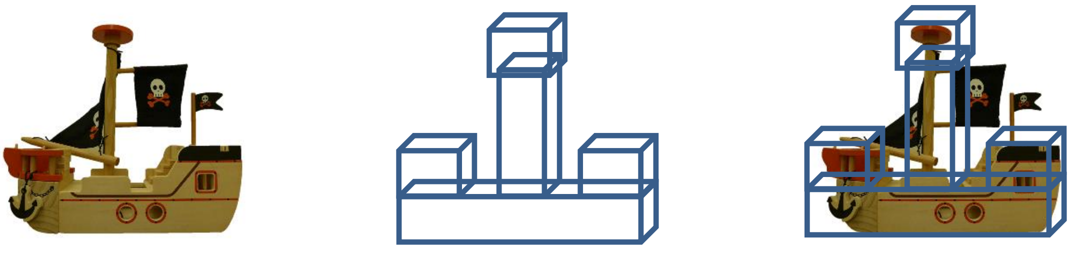


Figure 5.26 Simplified representation of the pirate ship for collision detection

After the PP had selected a UI cell, but before the move was carried out, the x, y and z coordinates would be compared against the internal representation to identify whether the move would result in a collision, if so, the move was ignored and an audible error message played to the PP.

5.15.3 The characters

The characters were placed within the scene at specific locations. In the case of the pirate ship the options were the bow, stern or crow's nest.

The characters (pirate or crab) comprised two main parts:

(1) The character

The characters used within the current study contained springs connecting the limbs to the torso. This helped to give the impression of animation while the characters were being gripped and moved by the robotic arm.

(2) Gripping platform

The characters were bonded at the base to a wooden 'gripping platform' with an anti-slip covering to aid robotic gripping. The platform provided a uniform easy to grip point for the robotic arm. It also ensured that the character was still visible to the user whilst being gripped and moved. The component parts of a character are shown in Figure 5.27.

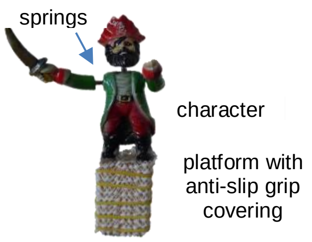


Figure 5.27 The component parts of a character

As with the setting, the characters were internally represented within the software to assist with collision detection. See Figure 5.28

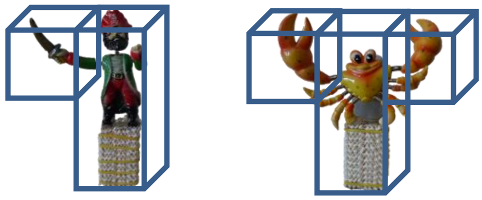


Figure 5.28 Character bounding boxes

5.15.4 Robotic system assistance

To support the PP with completing a story within ‘Scenarios’ the robotic system provided a range of assistance throughout the stages. This assistance included help with gripping objects, ‘attacking’ and ‘hints’.

5.15.4.1 Gripping

Manipulating the robotic arm into a position suitable for gripping the base of a character could be a complex process and lead to collisions, or a character being knocked from its location prematurely. For these reasons, the PP was provided with assistance by the system once the robotic arm’s gripper was near to the character.

Once the gripper had entered a region immediately surrounding the character (see Figure 5.29), the PP was informed that the robotic system could carry out the positioning sequence ready for gripping.

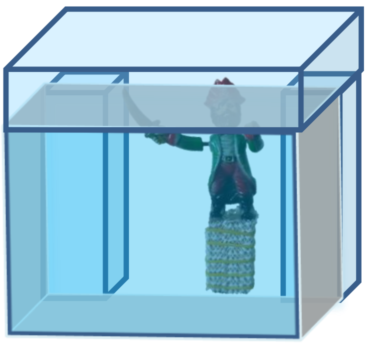


Figure 5.29 The area around the character

The PP could then select a user interface cell to ‘ask robot to do it’ (instruct the system to position the gripper ready for the PP to grip the character) - see Figure 5.30. The gripper would then be repositioned automatically. Depending on the current position, this may have involved several movements to reposition the arm ready for gripping.

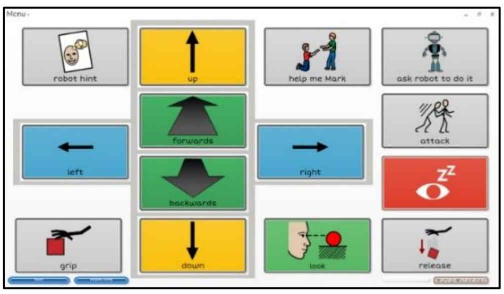


Figure 5.30 Graphical user interface for ‘Scenarios’

5.15.4.2 Attacking

Attacking was possible once the robotic arm was gripping the winning character and the gripper was positioned within the region immediately surrounding the losing character (see Figure 5.29).

The PP could then instruct the robotic system using the UI ‘Attack’ button (see Figure 5.30). The robotic arm would then ‘swipe’ the gripper at the losing character to knock it from the pirate ship. Once this had been done, the robotic arm would put the winning character in the losing character’s location.

5.15.4.3 Hint system

The PP could ask the robotic system for ‘hints’ i.e. suggestions about what the next command should be. The system would calculate the next move and then provide an audible instruction, for example ‘move forwards’. Additionally, the PP could request assistance from the researcher.

5.16 End of chapter summary

This chapter presented the technical implementation of both the robotics-based system and the haptic device. The component parts, flow of data and operation were described.

Following implementation, both were trialled by SPs before being used by the PPs.

Chapter 6 Assessment Design and Administration

6.1 Introduction

During this study an intervention was used with the PPs (see Intervention Design and Administration chapter). Assessments were needed which could measure specific aspects of the PPs' knowledge and abilities both before and after the intervention stage, with the aim of identifying the PPs' prior knowledge and abilities and any changes resulting from the intervention. No suitable assessments were found and so new ones were created. This chapter describes why existing assessments were unsuitable, the new assessments and how they were administered.

The intervention stage involved the PPs completing a set of tasks by manipulating the robotic arm in three dimensional space. The robotic system generated a haptic sensation in the PP's hand whenever the arm's end-effector gripped an object.

6.2 What needed to be assessed?

The intervention tasks involved knowledge relating to temporal, spatial and movement concepts. Thus, it was important to test this knowledge.

The use of a haptic device during the intervention meant that it was necessary to assess the PPs' ability to detect physical sensations in the palm area of their hands.

Broadly, two groups of assessments were required: 1. 'Cognitive' and 2. 'Physical'.

6.3 The new Assessments

Two separate assessments were contained within each assessment group:

(1) The 'cognitive' assessments consisted of: a) a static image-based assessment; and b) a video-based assessment.
(2) The 'physical' assessments consisted of: a) a physical touch assessment; and b) a haptic sensations assessment.

The order in which the assessment sessions were carried out and a description of the communication approach used with the TG PPs are first described, followed by an explanation of the assessments.

6.4 Assessment Sessions

All assessments were performed both before and after the intervention. Table 6.1 shows the number of assessment sessions by PP. Some of PP2's outcome assessments (the longer ones) were split over two sessions, as during the baseline assessments he appeared to fatigue.

Table 6.1 Assessment sessions

		Cognitive		Physical	
		Image-based	**Video-based**	**Touch**	**Haptic**
PP1	**Baseline**	1	1	1	1
	Outcomes	1	1	1	1
PP2	**Baseline**	1	1	1	1
	Outcomes	2 (AM & PM)	1	2 (AM & PM)	2 (AM & PM)

The assessment sessions were supported by two members of school staff. Before all assessment sessions, the supporting staff would be briefed by the investigator about their role during the sessions.

The PP would arrive at an assessment session seated in their usual wheelchair. At the start of the session, the PP would receive a briefing (from the investigator) about what would happen during the session. The investigator and a staff member would demonstrate the process so that the PP knew what to expect.

6.5 Methods used by the pupil participants to communicate and to indicate answers

The PPs of this study were non-verbal and also had profound motor impairments, which meant that they were unable to answer questions in conventional ways such as verbally, by pointing or by writing answers. Alternative approaches to communication and answer delivery were required.

Communication with this group may involve several alternative approaches including no-tech methods: the use of a communication book or an E-tran frame (see Appendix D - Figure D.1) combined with interpretation of the person's gaze direction; high-tech methods include VOCAs which incorporate eye gaze technology.

The PP's 'yes / no' response: Both participants looked to their right to indicate a 'yes' response and to the left for 'no'.

During the assessments the PPs used a combination of communication methods including an E-tran frame and gaze direction, and eye gaze technology.

NOTE: During the baseline physical assessments, it was discovered that PP2 was not as proficient at using an E-tran frame as was first thought, so the communication system was changed to the following method which was recommended by his SaLT: to indicate his left or right hand, PP2 would look at that hand; to indicate both hands, PP2 would look briefly at both hands in sequence; to indicate 'neither', PP2 would look upwards towards the ceiling. This was found to be a more effective approach.

6.6 Cognitive assessments (Spoken language comprehension)

6.6.1 Description of the new cognitive assessments

These assessments were designed to reveal the PPs' **existing** knowledge of a selection of physical world concepts (i.e. a baseline measure) and also to identify any **changes** in this knowledge following the intervention (i.e. an outcome measure). The assessments differed in the form of the concepts being assessed: a) the **static image-based** assessment evaluated the PPs' knowledge of concepts such as **position**, e.g. above, behind; and b) the **video-based** assessment examined the understanding of specific concepts involving **movement**, such as 'moving up'. The cognitive assessments also differed in some aspects of their administration procedure.

The research questions that these assessments were aiming to answer were:

RQ2 - How can the TG's knowledge of physical world concepts be revealed using technology?

RQ4.1 - Does the TG have pre-existing knowledge and abilities relating to the physical world?

RQ4.3 - Did the intervention develop the TG's knowledge and abilities relating to the physical world?

6.6.2 Common elements of the cognitive assessments

The cognitive assessments shared some common elements, now described, but there were some differences in the administration procedure which are described in the separate sections that follow.

6.6.2.1 The unsuitability of existing cognitive (spoken language comprehension) assessments

As previously established (in the Literature review chapter), existing spoken language comprehension assessment techniques were found to be unsuitable for use with the TG, and for the purposes of this research, largely due to accessibility issues. For these reasons, new (digital) bespoke assessments were created.

The TG are heavily reliant on Assistive Technology (AT) for communication and control but many existing assessments examined do not accommodate the needs of those who are non-verbal and more motorically impaired.

The static image-based assessment was designed to run within AAC software (Grid 3). Unfortunately, the video-based assessments could not be designed to run within AAC software as none was found which supported multiple video cells on a single page, and a 2 x 2 matrix of answer cells was a key feature identified for inclusion in the assessment at the design stage. This led to two separate cognitive assessments being developed.

A specific set of concepts needed to be assessed and, as far as could be ascertained, not all of these appear in existing assessments. Key concepts incorporated in the intervention were identified and selected for assessment.

6.6.2.2 The assessment design process

Both assessments were designed, implemented and tested by a team comprised of the investigator and five SaLTs. The design of the cognitive assessments described below was informed by the literature, current available assessments and the team's perception of the TG needs.

A subset of the SaLTs trialled and practised using the assessments in pairs – one adopting the role of SaLT and the other the pupil participant. This helped to refine the design of the assessments and to verify the administration process.

6.6.2.3 Outcomes from the design process

A fundamental aim of the assessments was that they should be AT accessible using eye gaze technology, the access method used by the participants of the study, and not require physical or verbal answers.

The design team also identified that:

(1) Actions can be difficult to convey using images alone and that short video clips may be better for representing such concepts. This is supported by the literature (Golinkoff et al. 1987);
(2) The assessments should follow the widely used 2 x 2 matrix presentation of answer cells;
(3) The assessments should be engaging so that the PP will want to do them;
(4) Assessor misinterpretation and bias should be minimised as far as possible.

6.6.2.4 Materials and methods

The cognitive assessments were administered using a personal computer with a 22" touchscreen monitor which was mounted on a height-adjustable mobile floor stand. An eye gaze camera was mounted magnetically to the centre of the lower edge of the monitor's frame (Figure 6.1). Stereo speakers were attached to the computer. The PC was running the Microsoft Windows 7 Operating System.

Figure 6.1 The hardware running the video-based assessment

All sessions were video recorded for the purposes of verification and analysis of the results.

Both cognitive assessments were of the quadrant forced-choice variety i.e. a 2 x 2 arrangement of cells with only one correct answer. No written word labels were presented for the answer cells, as spoken language comprehension was the focus of investigation.

The images used within the practice section of the static image-based assessment were selected from the libraries included with the Grid 3 software. The remainder of the images and all of the video clips were created by the investigator.

Many of the images and all of the video clips feature a toy dog character. This character was deemed by the development team to be age appropriate for a wide range of users.

The answer cell image designs were kept simple, often featuring a plain white or simple background and limited colour palette, helping to establish clear figure-ground.

Staff Present

Each assessment was administered by a SaLT and the investigator was also present for technical support and camera recording.

Within the school it is common for students to be assigned a SaLT, who can remain with them as they transition through their education. Each PP in this study had the same SaLTs for a period of years prior to the study and the assessments were administered by these SaLTs. The rationale for this was that: SaLTs are professionally trained in administering assessments; the SaLTs had in-depth knowledge of the participants and their communication needs; and they had a good working relationship with the PPs, which was important for putting them at ease.

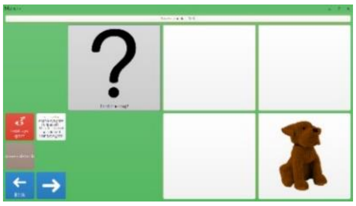
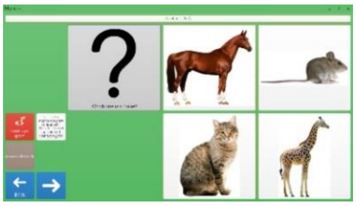
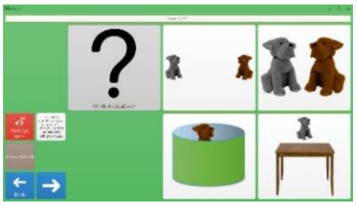
Cognitive assessment administration procedure (common elements)

During the assessments, the SaLT would stand to the left of the PP. The PP would be facing the monitor. The static image-based assessment was always administered first and the video-based assessment second.

6.7 Static image-based assessment

This assessment was built to work within the Grid 3 software (Smartbox Assistive Technology Limited 2016) running on the Microsoft Windows 7 Operating System. The typical format of the assessment screens or ‘panels’ is shown in Table 6.2. The assessment is a ‘grid set’ within Grid 3 and inherits all of the accessibility features of Grid 3 including, crucially for the current study, support for eye gaze and synthesised speech output. Automatic answer logging was achieved by linking a vbScript code file to each of the assessment cells using Grid 3’s Computer Control ‘start program’ function.

Table 6.2 Examples of the three stages of the static image-based assessment (the number in parentheses indicates the number of questions in that stage)

1. Access check (4)	2. Practice (3)	3. Assessment question (17)
		

6.7.1 Static image-based assessment administration procedure

This image-based assessment comprised a total of 24 questions divided into three parts:

(1) Access check

The SaLT first completed an access check with the examinee (Table 6.2 - 1). This was to ensure that the PP could access all four of the answer cells on the right-hand side of the screen. The PP was required to answer all four of the questions correctly before proceeding to the next stage. For each of these questions an image of the dog character appeared in only one cell of the main grid of four answer cells (the rest of the answer cells were blank). The question “Find the dog?” was generated by the digital assessment using the Grid 3 speech synthesis capability.

(2) Practice

The SaLT then asked the PP three practice questions, to enable the PP to become familiar with the format of the assessment (Table 6.2 - 2). For each of these questions, four possible answers appeared, only one of which was correct. The questions and answers related to nouns and the question “Which one is the…?” was generated by the digital assessment.

(3) Main assessment questions

The SaLT then asked the participant to complete the main 17 assessment questions (Table 6.2 - 3). These followed the same format as the Practice questions but now related to prepositions and adjectives (colours). The digital assessment generated questions of the format “Which one is…?”. The concepts tested are listed in Appendix B and Appendix M - Table M.1.

The SaLTs administered the assessment by following a written assessment procedure (Appendix Y- Y.1). The PP’s SaLT first explained and then administered the assessment to the PP, helping them to work through and regulate the pace of completion, thereby reducing the likelihood of accidental selections (Jacob 1990). The pace was regulated using touch-only activated cells which toggled whether eye gaze control was activated or deactivated and, therefore, whether PP selection of cells was possible.

The examinee provided answers by ‘dwell-selecting’ i.e. fixating their gaze upon a single cell for a brief time. The assessment would then automatically log their answer and move on to the next question.

Questions were ‘read out’ using the speech synthesis feature of Grid 3. Each question was read out twice. The examinee could select a cell to hear the question again if necessary.

The logged answers were stored in a spreadsheet format file (see Appendix U for a sample).

6.8 Video-based assessment

At the time of the present study, no communication software was identified which provided support for four eye gaze accessible video cells on a single screen (a requirement of the present study). The closest match to this behaviour was found in the ‘video wall x 4’ activity of the Look to Learn software (Smartbox Assistive Technology Limited 2018). However, this only provides a single page of videos and two pages were needed for this study. This page can be edited and the videos changed, but doing so during the assessment would interrupt the flow. For these reasons, the video-based assessment discussed here was created by the author using the Microsoft Visual Studio programming language C# (Microsoft 2019).

The assessment contains just two pages and four questions per page. Each page contains a grid of four video answer cells (see Figure 6.2). Each video clip is between two and four seconds in duration, with no audio.

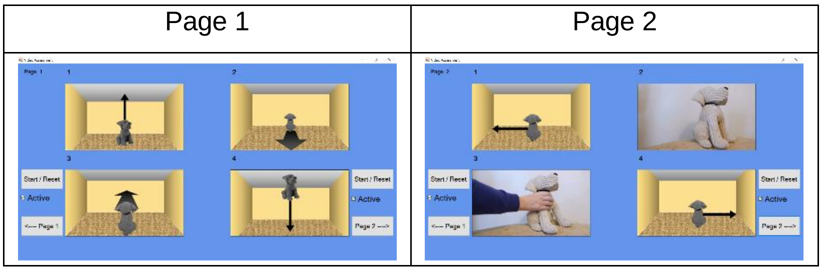


Figure 6.2 Video-based assessment: The two pages

The concepts represented within the video cells are: Page 1: 1. Moving up; 2. Moving backwards; 3. Moving forwards; 4. Moving down; Page 2: 1. Moving left; 2. Gripping; 3. Releasing; 4. Moving right. The majority of the video clips are animations constructed by the author. The ‘gripping’ and ‘releasing’ video clips are both live recordings created by the author.

Once eye gaze control had been activated by the SaLT, each video cell would animate when the examinee’s gaze fell within its boundaries, but paused if gaze moved outside of the cell, resuming when gaze focus returned. Upon completion, the video clip would pause (showing a black frame), ‘rewind’ and then play from the beginning. Figure 6.3 shows the first and final frames of the ‘moving forwards’ video clip.

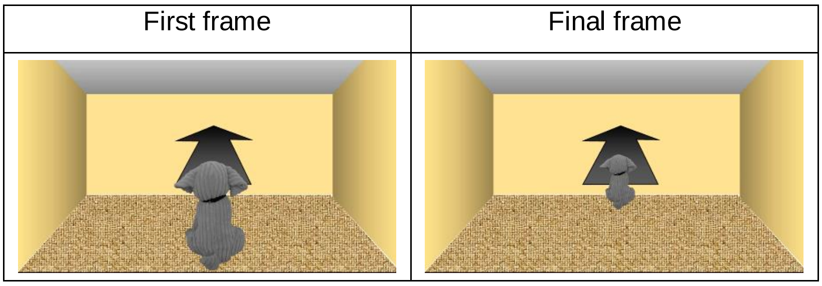


Figure 6.3 Video-based assessment: First and final frames of the ‘moving forwards’ video clip (Page 1, bottom-left cell)

6.8.1 Video-based assessment administration procedure

After a brief explanation from the SaLT about what the assessment entailed, and an eye gaze calibration process, each participant completed a total of eight assessment questions. This time the SaLT read aloud questions of the format “Which one is…?” and recorded responses manually. The administration procedure for this can be found in Appendix Y - Y.2.

Differences between the video and static image-based assessments

There were a number of key differences in the design and administration procedures of the two assessments. These are summarised in Table 6.3. The main reason for these differences is:

(1) Grid 3 natively contains a large range of features including speech synthesis and extensive accessibility options. The static image-based assessment inherited these features.

(2) At the time of the study, Grid 3 did not support the use of four video cells per page. For this reason the first author implemented the video-based assessment software. It was not possible to implement all of the features contained within Grid 3 in the time available.

Table 6.3 Differences between the static-image and video-based assessments

	Static image-based	Video-based
Method of question delivery	Synthesised speech – via The Grid 3. The participant can also activate a cell to listen to the question on demand.	The SaLT reads the questions aloud
Answer selection method	Dwell-click (briefly fixating on an answer cell)	Continuous fixation. The SaLT determines which cell is being attended to based on the position of a visible cursor
Access check	4 questions, carried out through the digital assessment	No questions, the check was carried out by the SaLT (by visual observation)
Practice questions	3 questions, carried out through the digital assessment	None (assumed carry-over from previously completing the similar format static-image based assessment)
Recording of answers	Automatically by the digital assessment	Manually – by the SaLT
Answer cell type	Static image	Animation or video

6.9 Physical assessments

The main aim of the physical assessments i.e. both the **physical touch** and the **haptic sensations**, was to identify the PP's ability to accurately identify whether physical touch or haptic sensations were being delivered to the palm area of their left hand, right hand, both hands, or neither hand.

It was considered important to know how well the participants could identify sensations in the palm area of their hands since the robotic system incorporated haptic feedback to provide the PPs with a sense of gripping. It was also considered important to discover whether the PPs experienced any adverse reactions to the haptic sensations.

The assessments were also designed to identify whether the PPs had better sensitivity in one hand than the other, with the intention that their most appropriate hand could be used during the intervention.

The physical touch assessments formed a baseline against which the haptic sensations assessments could be compared. The haptic sensations used in this research are based on vibration which stimulates / 'innervates' different receptors in the skin to physical touch (pressure). One or other of these types of receptors may not have been functioning correctly in the PP due to damage to their Central Nervous System (CNS).

Performing both physical touch and haptic sensation assessments allowed a comparison of the results between these two modes of sensation delivery.

6.9.1 Physical touch assessment

The **physical touch** assessment was designed to identify the PP's ability to accurately identify **physical** touch in the palm area of their hands.

At the time of the study the degree to which the PPs were able to detect physical touch sensations in the palm area of their hands was unknown. To the author's knowledge (and that of the staff at VEC) this had never been ascertained. Damage to the CNS resulting from the PP's condition may have adversely affected this ability.

The physical touch assessment was designed to identify the PP's ability to detect whether touch sensations were being delivered to the palm area of their left hand, right hand, both hands, or neither hand.

The new physical touch assessment involved concealing the PP's hands and then physically touching the palm area of either, both or neither of their hands and then asking the PP to indicate what they thought had happened.

The research question that this assessment aimed to answer was:

RQ1.1 "Is the TG able to detect and correctly identify real physical touch sensations in the palms of their hands?"

6.9.1.1 The unsuitability of existing physical touch assessments

Often a person's skin sensitivity and ability to detect touch is assessed (by clinicians / therapists) using the 'pin prick' technique. This involves applying pressure to various parts of the skin using a pointed object such as a safety pin or cocktail stick (New York University School of Medicine 2006; University of Nottingham 2007).

The author and therapy staff deemed this approach unsuitable for the PPs who were the subjects of this research: PP1 had involuntary movement which could have made the pin prick approach hazardous; PP2 had a heightened startle reflex which was likely to have been triggered by the 'pin prick' technique (Ayres and Tickle 1980).

For these reasons a safer, more suitable physical touch assessment was developed for the PPs.

6.9.1.2 The assessment design process

The assessment was designed specifically for the TG. The aim was to assess them in a comfortable manner. VEC staff were consulted with regarding the design of the assessment through a series of trials. This helped to refine the design of the assessment and to verify the administration process.

The design process resulted in an assessment which accommodated both the communication and physical needs of the TG.

6.9.1.3 Materials and Methods

The PP's hands would be concealed behind a curtain - a height adjustable horizontal pole with a black towel draped beneath it (see Figure 6.4). The pole and curtain were positioned in front of the PP and the height adjusted to prevent the PP from seeing their hands and, therefore, which hand(s) if any were being touched during the assessment, i.e. they had to provide answers based on 'feel' alone.

Figure 6.4 The concealing equipment

The two symbols attached to the pole in Figure 6.4 represent 'Yes' (left) and 'No' (right). These were to remind the investigator of the direction of the PPs 'Yes / No' responses during the assessment.

PP1 had involuntary movement, and so an LSA was required to steady his arms and hands during the assessment so that the investigator could touch his hands, and to prevent the curtain from being lifted (see Figure 6.5).

Figure 6.5 PP1's hands and arms being steadied by an LSA

PP2 had spasticity and contractures which caused his hands to constrict. An OT supported PP2's hands and helped to keep them in an 'open' position ready for touching by the investigator during the assessment (see Figure 6.6).

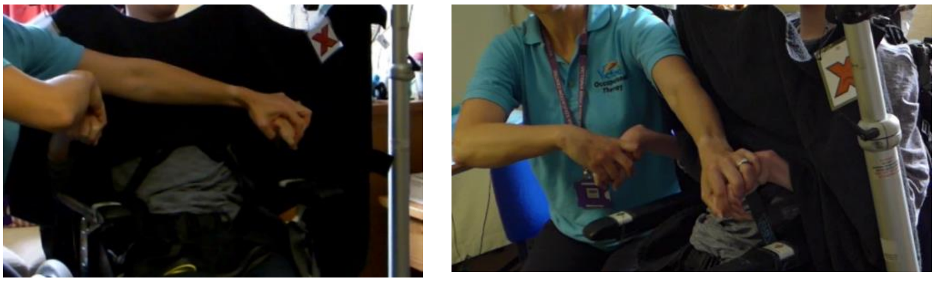


Figure 6.6 PP2's hands being held open by an OT

The investigator wore gloves during the assessments for hygiene reasons.

Staff present

During the assessments, in addition to the investigator, there would be two other members of school staff present, depending on which PP was being assessed:

PP1:

(1) The investigator (to perform the physical touching of the hands);
(2) An LSA (to support/hold the PPs hands and arms);
(3) A SaLT or SaLTa (to facilitate communication and obtain answers).

PP2:

(1) The Investigator (to perform the physical touching of the hands);
(2) An OT (to support and open PPs hands);
(3) A SaLT or SaLTa (to facilitate communication and obtain answers).

Physical touch assessment administration procedure

The investigator would begin each session by explaining the format of the session to the PP and the supporting member of staff.

Before each question, the investigator would ask the communication staff member to "Look away and let me know when you have done so". The investigator would then inform the PP that he was going to touch either one of their hands, both of their hands or none of their hands", showing symbol cards (see Appendix D - Figure D.2) to the PP for each option. The investigator would then carry out the relevant operation and then ask the PP to communicate their answer to the communication staff member. The investigator would then note the answer.

The answering method used was an E-tran frame, but this needed to be changed to another method for PP2 (see Section 6.5).

Figure 6.7 The Investigator touching PP2's left hand

6.9.2 Haptic sensations assessment

The **haptic sensations** assessment was designed to identify the PPs ability to identify **haptic** sensations in the palm area of their hands. Haptic feedback devices are not usually used with the TG. No existing suitable assessments were found and so a new one was created.

The haptic devices developed for this study used vibration. Vibration 'innervates' different skin receptors to those involved in pressure-based physical touch.

The aim of the haptic sensations assessment was similar to that of the physical touch assessment but in this instance it was to identify the PP's ability to detect whether **haptic** sensations were being delivered to the palm area of their left hand, right hand, both hands, or neither hand.

This assessment involved attaching the haptic feedback devices to both hands of the PPs and then activating either, both or neither of the devices and then asking the PP to indicate what they thought had happened.

6.9.2.1 The research question that this assessment aimed to answer

RQ1.3 "Is the TG able to detect and correctly identify haptic sensations in the palms of their hands?"

6.9.2.2 The assessment design process

Nine different haptic prototypes were created using a variety of materials and approaches. All designs were vibrotactile in nature as this is a low-cost and relatively simple method of producing rudimentary haptic sensations. The designs were differentiated based on which area(s) of the hand received sensations. This depended, to an extent, on how the device was attached and the movement that a person had in their hands and fingers and thus which areas of the hand came into contact with the prototype. The approaches used were: 1. Palm-based; 2. Grip/clench-based; 3. Whole hand-based; and 4. Digit-based (see Section 8.2.2 Table 8.1).

6.9.2.3 Outcomes from the design process

Each of the nine prototypes were trialled with the SPs and feedback gathered. This process led to the elimination of seven prototypes - narrowing down to the two prototypes deemed most suitable: one was palm-based, the other digit-based. These were then trialled with the SPs to measure their ability to identify the location of the haptic sensations and to identify which of the two devices was the most appropriate for use with the TG. Two of the palm-based prototypes were used in the trials with the SPs, one on each hand, whereas the digit-based prototype involved just one of the SP's hands, with a device attached to the tip of each digit, and sending sensations to each digit on that hand.

Based on analysis of the feedback from the design process, one of the prototypes (7) deemed most suitable for use with the PPs was selected for use during the assessments and intervention stages. Recommended / preferred haptic strengths and patterns were noted.

6.9.2.4 Haptic fitting

In March of 2017 both PPs had a 'haptic fitting' session. This was to introduce them to the haptic device that would be used during the haptic sensation assessment and the intervention, and to see if there were any issues.

6.9.2.5 Materials and Methods

Equipment

Figure 6.8 provides an aerial view of the equipment configuration for the haptic sensations assessment. The haptic sensations system was comprised of:

(1) A computer running the Microsoft Windows 7 operating system and containing Bluetooth wireless capability;
(2) 2 purpose-built palm-based haptic devices with Bluetooth wireless controller units;
(3) A height adjustable curtain (for screening purposes) – the same as used in the physical touch assessment;
(4) Communication symbol cards.

Figure 6.8 Aerial view of the haptic control setup

System operation description

The haptic devices used in the haptic sensations assessment were controlled wirelessly from the computer. This computer contained the control interface (see Figure 6.8) for controlling the palm-based haptic devices.

Components attached to the PPs

A haptic device would be attached to each of the PP’s hands using elasticated hook and loop straps (see Figure 6.9) and the cable channelled through each of their sleeves up to their collar, and then out and over the back of their wheelchair to avoid tangling.

Each of the hand-based haptic devices were physically attached to a wireless control unit.

Wireless haptic control unit

The other end of the cable from the haptic device was plugged into the wireless control unit. The control units were connected to a controlling computer over wireless (Bluetooth) connections.

Controlling computer

The computer communicated with each of the hand-based haptic devices via the wireless control units.

Interface

The computer was running the Grid 3 software which contained an interface for controlling the haptic devices (see Figure 6.10). Once an interface cell had been activated, a command would be sent to one or both of the haptic controllers, which then relayed sensations to the haptic device(s).

PP1	PP2
	

Figure 6.9 The haptic device attached to PP1 and PP2’s hands

During the assessment, the PP is positioned on the other side of the curtain, facing towards the curtain.

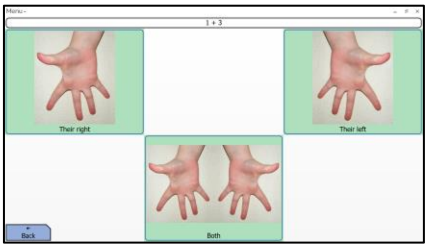


Figure 6.10 The interface used to initiate the sending of haptic sensations

The audio of the computer was muted to avoid the PP hearing selection clicks or, more importantly, no click if neither of the haptic devices was activated (although the investigator would still click the computer mouse for 'neither' to prevent the lack of an audible mouse button click from being interpreted by the PP as 'neither').

The PP's hands were not concealed from them on this occasion as there was no reason for them to be. The horizontal pole and towel were used to shield the equipment area from the PP, so that they could not see what the investigator was doing.

PP answering method:

The PPs indicated their answers using an E-tran frame with a communication partner and by looking at their hands. PP2 encountered issues with this method and so it was changed partway through (see Section 6.5).

Staff present

During the assessments, as well as the investigator, there would be two other members of school staff present:

PP1:

(1) The investigator (to control the haptic devices to deliver the sensations and note answers);
(2) An LSA (to assist with the fitting of the haptic device);
(3) A SaLT or SaLTa (for communication and taking answers)

PP2:

(1) The investigator (to control the haptic devices to deliver the sensations and note answers);
(2) An OT (to fit the haptic device);
(3) A SaLT or SaLTa (for communication and taking answers)

Haptic sensations assessment administration procedure

(1) The supporting staff and PP enter the room.
(2) Briefings are given by the investigator to the supporting staff and PP.

(3) The investigator and supporting staff attach the haptic devices to the PP's hands (palm side – see Figure 6.9).

(4) The investigator would then carry out the assessment by doing the following:

a) Saying to the PP: "I'm going to send a sensation to one of your hands, both of your hands, or none of your hands" and accompany this by showing the PP symbol cards. This approach is called 'total communication' and can help those who have disabilities to understand what is being communicated to them (see Appendix D - Figure D.2).
b) Saying to the PP: "1..2..3".
c) The investigator would then issue the relevant command via the interface, being careful not lean towards or look in the direction of the chosen option.
d) The investigator would then ask the PP to give their answer to the member of staff present who was responsible for taking the PP's answers.
e) The investigator would then note down the PP's answer.

6.10 End of Chapter Summary

To summarise, assessments were required to establish baseline and outcomes scores to measure potential changes resulting from the intervention.

Assessments were needed which measured the PPs' ability to identify physical sensations in the palm area of their hands. Additionally, assessments were needed which could evaluate the PPs' knowledge of specific language concepts.

Existing assessments were found to be unsuitable and so new assessments were created. VEC staff helped to create and trial these new assessments prior to them being used with the PPs.

All assessments were used with the PPs both before (baseline) and after (outcomes) the intervention stage. The results of all assessments, both baseline and outcomes are presented and discussed in the Results and Discussion (Pupil Participants) chapter.

Chapter 7 Intervention Design and Administration

7.1 Introduction

This chapter describes the purpose, design and administration procedures for the intervention undertaken in this study. The intervention stage came between the baseline and outcomes assessments and consisted of a series of tasks which the pupil participants (PPs) were asked to complete using the robotics-based system described in the Technical Implementation chapter. Some of the tasks incorporated haptic feedback using the palm-based device (see Technical Implementation chapter) to provide the PP with a rudimentary tactile experience while the robotic arm was gripping an object. The PPs could request assistance to help them to complete the tasks if required, either from the investigator or, in certain instances, the robotics-based system.

7.2 Purpose of the Intervention

The purpose of the intervention was to reveal and build upon the knowledge and abilities of the TG in the context under investigation to address the Overarching Research Question and Overarching Research Aim (see Introduction chapter), and restated here:

> **Overarching RQ:** How can the TG's knowledge and abilities relating to the physical world be revealed and developed using technology?
>
> **Overarching RA:** To use suitable assessment techniques to reveal the TG's knowledge and abilities relating to the physical world and to develop these using a robotics-based system.

and RQ 2, RA 2, RQ 4 and RA 4:

> **RQ 2:** How can the TG's knowledge of physical world concepts be revealed using technology?
>
> **RA 2:** To reveal the TG's knowledge of physical world concepts.
>
> **RQ 4:** Does the intervention reveal and develop the TG's knowledge and abilities relating to the physical world?
>
> **RA 4:** To reveal and develop the TG's knowledge and abilities relating to the physical world by employing the intervention.

Specifically, these tasks were designed to ascertain a range of information about the PPs, including their ability to identify certain colours, their knowledge of physical concepts, level of spatial awareness, and capacity to formulate a solution to a problem and carry it out. It is difficult to ascertain this information using conventional assessment methods.

An important point of note is that these tasks were intended to help the PPs to develop an awareness of their knowledge and capabilities, and to build on these.

The PPs' use of the system to complete the tasks was also intended to evaluate the efficacy of the system.

The intervention was also used to obtain a proxy measure of the workload experienced by the PPs during the completion of the tasks using the NASA Task Load Index (see Appendix H).

Some of the activities described here are based on the play that typically developing children engage in with blocks, such as putting them into a container or knocking down towers of blocks (Harwin et al. 1988; Sheridan et al. 1999). The TG will not have had these opportunities as they will not have been able to grip and manipulate blocks in their hands.

The 'Scenarios' task group involved the creation and enactment of a story and enactment using the robotics-based system. Story creation and enactment using robotics by young people who have disabilities has been carried out previously (Adams et al. 2008).

7.3 About the task groups

There were three main task groups: 'Cubes', 'Directions' and 'Scenarios'. Each of these groups contained a series of tasks:

(1) **'Cubes'**: This task group consisted of 'pick and place' tasks and incorporated haptic feedback (see Technical Implementation chapter and Intervention Design and Administration chapter).

(2) **'Directions'**: This task group contained two parts: 1) '**Feed the giraffe**': a PP familiarisation exercise that involved using the robotic arm to 'feed' a toy giraffe; 2) '**Towers**': here the PPs manoeuvred the robotic arm to demolish various structures. Neither of these two parts involved haptic feedback as no 'gripping' was involved.

(3) **'Scenarios'**: This task group involved interactive story creation and enactment using the robotics-based system and incorporated haptic feedback.

The degree of challenge increased throughout the task groups and the ratio of PP to robot autonomy shifted from low to high PP autonomy (see Table 7.1).

Table 7.1 PP / Robot autonomy and assistance available during tasks

	PP autonomy	Haptic Feedback	System assistance	Help available
Cubes	Low	Yes	Yes	Investigator
Directions	High	No	No	Investigator
Scenarios	High	Yes	Yes	Robot / Investigator

A careful balance needed to be maintained when setting tasks for the TG. The TG are a vulnerable group of individuals. The level of challenge needed to be sufficiently high, but not so high that it caused them distress or discomfort.

The completion of the tasks did not require any physical movement, other than eye movements, to control the GUI. However, for the PPs, maintaining their head position or attempting to keep involuntary movement in check while using an eye gaze system may be physically fatiguing.

If a PP exhibited any adverse reactions during a session the investigator would make a judgement about whether to rearrange the order of tasks, omit tasks, or even end the session if deemed necessary. Thus, not all elements of the tasks were completed by both PPs. Differing ability levels were identified within the two PPs, and some tasks were considered too challenging for PP2. Table 7.2 shows which tasks were carried out with PP1 and PP2.

Table 7.2 Tasks carried out with the PPs

Task Stage	Session No.	Part No.	Name of task element	*Task elements completed	
				PP1	**PP2**
Cubes	1	1	Familiarisation	Completed	Completed
	2	2	Tasks	1-14	1-14
	3	3	Tasks	15-27	15-20 (not 21-27)
Directions	4	1	Giraffe	Completed	Completed
	5	1	Towers	1-6	1-6
	6	2	Towers	7, 8, 9, 11, 13 & 15	7, 8 & 9
	7	3	Towers	10, 16 & 14	11, 13, 15, 10, 16, & 14
	8	4	Towers	17, 18, 12 & 19, 20, 24	17, 18, 12 & 19, 20, 24
Scenarios	9	1	Pirate ship	Completed	Completed
	10	2	Pirate ship	Completed	---

* See Appendix P (PP1) and Appendix Q (PP2) for a description of the tasks completed

7.4 Materials and methods (common to all task groups)

7.4.1 Equipment

For all of the task groups, the layout and experimental setup was fundamentally the same (i.e. the position of the PP, the AOO etc.). Please see Technical Implementation chapter which describes the equipment setup. However, there were variations between task groups and tasks, including whether haptic feedback was involved, the objects placed within the scene, the GUI used and so on. These differences will be described under each of the relevant sections.

7.4.2 Intervention Procedure

There were common elements to the format of the intervention sessions. Deviations from this format will be explained under the relevant sections.

(1) **Briefing:** At the beginning of each session the investigator would brief the PP and LSA about the session, i.e. provide an explanation of the tasks and what the PP would be required to do.

(2) **Demonstration:** In the first session of a task group the investigator, and sometimes a member of staff, would provide the PP with a demonstration of what they would be doing during the session so that the PP knew what to expect.

(3) **Haptic device:** Haptic feedback (described in the Technical Implementation chapter) was involved during the 'Cubes' and 'Scenarios' task groups only. The haptic device would be fitted to the palm of one of the PP's hands before commencing the tasks.

(4) **Practice:** The PP would have a short practice period.

(5) **Configuration:** At the start of each task the investigator would place the objects to be manipulated within the scene, for example wooden blocks or toy characters. The correct user interface would be chosen and the relevant software configured.

(6) **PP completion of tasks:** The PPs would be asked to complete a series of tasks by instructing the system to manipulate objects within the scene.

(7) **Forms:** After each set of tasks or, in some cases, after each task, the accompanying LSA would be asked to complete paperwork relating to aspects of the session.

PPs session rating: At the end of sessions, the investigator would ask the PP to rate how they felt about the session using a 'Smileyometer' (see Figure 7.1). The Smileyometer utilises a Likert scale approach and uses symbols which makes them suitable for use with those who are not literate. The investigator would point to each option in turn beginning with 'Awful' and saying 'this one?', until the PP gave a 'yes' response.

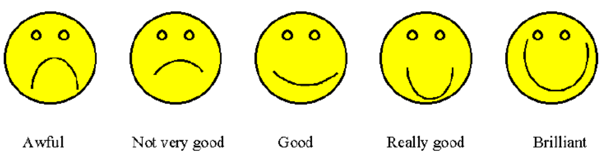


Figure 7.1 'Smileyometer' (Read et al. 2002)

Each session was video recorded from two different angles simultaneously (using two video cameras) for later analysis.

The three groups of tasks i.e. 'Cubes', 'Directions' and 'Scenarios' will now be described individually.

7.5 ‘Cubes’

7.5.1 Introduction

The ‘Cubes’ task group contained ‘pick and place’ tasks. The PPs used the robotic system to pick up and place coloured cubes into a box as requested by the investigator. The PP would receive a haptic feedback sensation for the duration of a cube being gripped.

These tasks involved a low level of PP autonomy i.e. the robotics-based system would carry out all of the individual movements required to place the cube in the box once a cube had been selected at the interface.

The ‘Cubes’ tasks included haptic feedback which was delivered during the ‘gripping’ stage via the palm-based haptic device (see Technical Implementation chapter) worn by the PPs on one of their hands.

‘Cubes’ was comprised of three separate sessions. The first was a familiarisation session and the second and third involved the actual tasks.

The familiarisation stage was designed to introduce the PPs to the format of the research sessions and for them to become accustomed to the robotics-based system i.e. how it moved, the noises that it made, and how it was operated using the interface.

The ‘Cubes’ tasks were primarily designed to identify the PP’s ability to: 1. Identify three colours: yellow blue and red; 2. Follow a sequence of instructions, for example, “this one, then that one”; 3. Identify the relative positions of objects, for example, left or middle; 4. Complete a task in a specific order, for example, starting from the left.

7.5.2 Materials and methods (‘Cubes’)

Three coloured wooden cubes placed on wooden plinths were positioned on a raised area of the scene as shown in Figure 7.2.

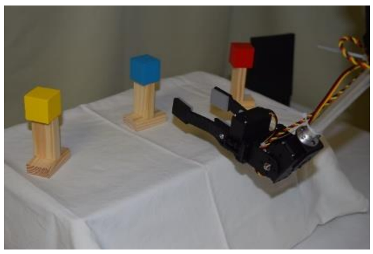
1	2 (Detail)
	

Figure 7.2 Scene setup for ‘Cubes’

The ‘Cubes’ interface (see Table 7.3) contained cells depicting images which represented the three cubes (a) and (b). The interface also contained cells for the PP to: (c) request assistance from the investigator; (d) view the live scene; (e) activate / deactivate eye gaze control. Upon selection of a cube or 'look' cell, a live camera stream of the scene was presented at the interface for a period of several seconds (see Figure 7.3).

Table 7.3 'Cubes' interface

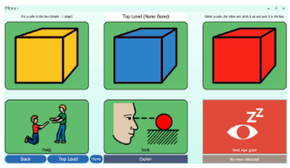
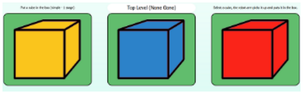
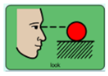
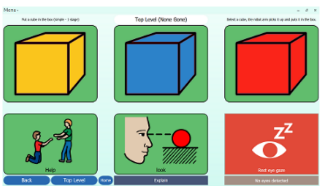
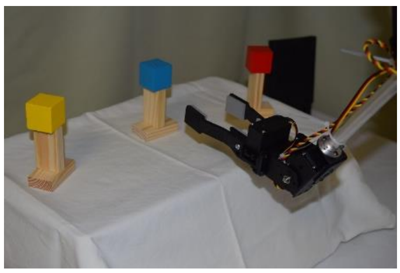
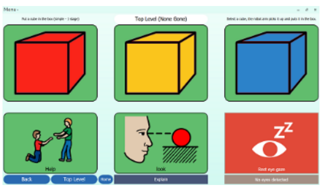
(a) Interface	(b) Cube cells	(c) Help	(d) Look	(e) Activate / Deactivate eye gaze control
				

Figure 7.3 Live view (with anonymised participant)

Over the course of the three cube sessions, two versions of the interface were used. In the first version of the interface, the positions of the cube cells mapped directly to the positions of the real cubes in the scene (Table 7.4 (1)). In the second version (Table 7.4 (2)), the positions of the cube cells have been rearranged so that they no longer map directly to the real cubes in the scene.

The purpose of the second version of the interface (Table 7.4 (2)) was to identify whether the PPs were still able to identify and select the requested cubes, even though the position had changed at the interface (and so no longer matched the positions within the real scene).

Table 7.4 'Cubes' interfaces

Interface No.	(a) User Interface	(b) 'Live' scene
(1) (direct mapping to real cubes)		
(2) (mixed – does not map to real cubes)		

The robotic arm started from a 'home' position and returned to this position after the task had been completed (see Table 7.4 (b)).

7.5.2.1 Procedure

The investigator would ask the PP a question relating to the concepts in Appendix B (Table B.1 – 'Intervention' - 'Cubes'). The PP would then select a cell containing an image of a coloured cube from the UI (see Table 7.4 (1)).

No further input was required from the PP. The system would instruct the robotic arm to move to and grip the relevant cube. The arm would then move the cube over the box (see Figure 7.4) and then release the cube into the box. While the robotic arm gripped the cube, the PP received a haptic sensation from the haptic device attached to their chosen hand. The robotic arm would then return to the 'home' position.

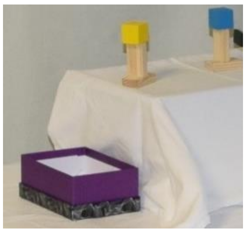


Figure 7.4 The box in which the cubes were placed

Once a cube had been put into the box, the user could subsequently select the same cube via the interface, and the arm would carry out the associated sequence of movements, the difference being that the PP would not receive a haptic sensation during the robotic arm's gripping stage.

Once the PP had given their answer, the investigator would record this and inform the PP whether the answer was correct or incorrect. If the answer was incorrect, the investigator would explain why to the PP.

One NASA-TLX form (see Appendix H) was completed by the accompanying LSA for the whole of each session for each PP.

The list of tasks carried out by the PPs together with their answers during the 'Cubes' task group can be found in Appendix P (PP1) and Appendix Q (PP2). The results are presented and discussed in the Results and Discussion (Pupil Participants) chapter.

7.6 'Directions'

7.6.1 Introduction

The 'Directions' tasks involved the PP manoeuvring the robotic arm in 3D space using direction commands of left, right, up, down, forwards and backwards. The task group consisted of a familiarisation activity of 'feeding' a toy giraffe and then 'Towers' sessions, which involved knocking down structures built from wooden blocks. The structures were placed in various locations within the scene, requiring increasingly complex solutions.

These tasks involved a high level of PP autonomy i.e. the PP would perform all of the individual robotic arm movements.

The haptic feedback device was not used during these tasks as no gripping of objects occurred.

'Directions' was comprised of three separate sessions. The first was a familiarisation session and the second and third involved the actual tasks.

The 'Directions' task group consisted of two parts: 1) a warm-up/familiarisation exercise referred to as 'Feeding the giraffe'; and 2) 'Towers' which contained the actual tasks. These two parts were designed to familiarise the PPs with control of the robotic arm in three dimensions and to then identify their ability to control the robotics-based system to complete the tasks.

Feeding the giraffe: The PP used the system to 'feed' the toy giraffe by taking 'leaves' to it. This was a 'fun' session to provide the PPs with no-pressure practice.

'Towers': The goal of the 'Towers' task was for the PP to demolish structures assembled from wooden blocks. This stage examined the PP's ability to formulate a solution to a problem and carry it out.

7.6.2 Materials and methods ('Directions')

During the 'feeding the giraffe' session, the scene contained a toy giraffe (see Figure 7.5). Food (plastic leaves) was tied to the robotic arm's gripper. The investigator moved the giraffe to various locations within the scene and the PP was asked to feed the giraffe using the leaves attached to the gripper. Feeding animals is a popular activity with young people and has been used in studies involving robots and children who have disabilities (Encarnação et al. 2012b).

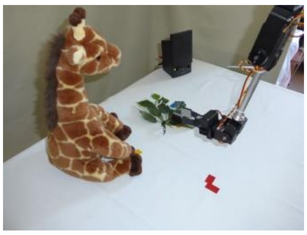


Figure 7.5 'Feeding the giraffe'

This provided an opening (icebreaker) activity, helping to introduce the PP to the control of the robotic arm in three dimensions using all direction controls. It also helped the investigator to observe and gauge the PP's current level of skill in a low pressure manner.

The full range of interface direction controls were provided during 'feeding the giraffe' (see Figure 7.6). The PP was presented with an onscreen view of the scene via the camera whilst commands were being carried out.

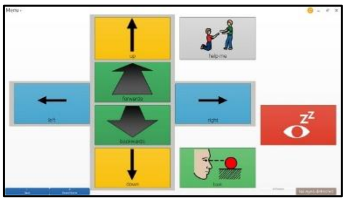
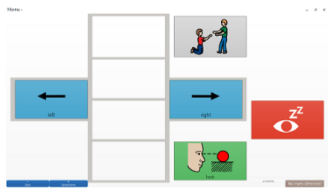
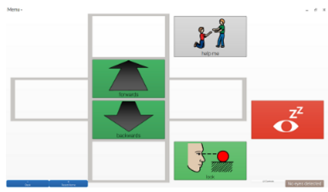
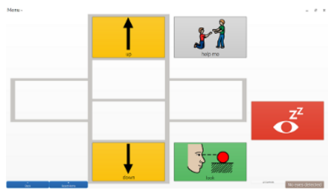
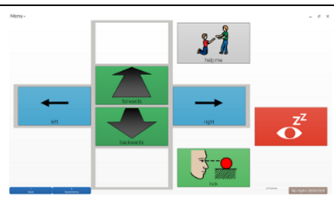


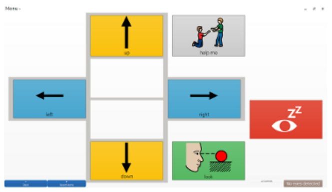
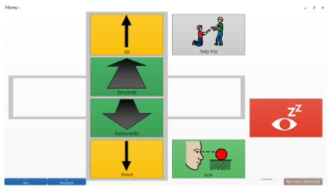
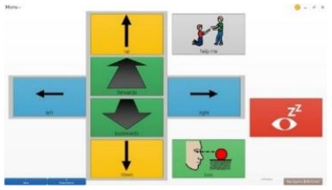
Figure 7.6 Interface controls for 'Feeding the giraffe'

During the 'towers' stage a similar pattern was used: a tower or structure would be built by the investigator in the scene. The PP would be asked to use the robotic arm to demolish the construction. In one task a stick was tied to the gripper to assist with the task (task 12). Please refer to Appendix W for details of the tasks.

Only the controls required to complete the specific task and their opposites were presented at the interface i.e. if only movements to the left were required, then only the left and right controls would be available at the interface (see Table 7.5 – 'Left and Right only'). The early tasks in this group had just two direction controls displayed on the interface, increasing to four in later tasks and finally all controls in the final tasks. As the tasks progressed, the constructions were positioned in areas which required greater planning skills to demolish.

Table 7.5 Command pages

Left and Right only	
Forwards and Backwards only	
Up and Down only	
Left, Right, Forwards and Backwards only	

Left, Right, Up and Down only	
Forwards, Backwards, Up and Down only	
All controls	

7.6.2.1 'Towers' - Procedure

The goal of the 'towers' tasks was to use the robotic arm to demolish a variety of towers and structures made from wooden blocks.

Once the investigator had assembled the structure for the task, the starting position of the arm would be configured. The starting position of the robotic arm was dependent upon the specific task. For example, if the task was to demolish a structure underneath the robotic arm, the robotic arm would start in a high position.

The appropriate UI would be selected for the task by the investigator and the PP asked to demolish the structure.

For details of the 'Towers' tasks please see Appendix W.

The results are presented and discussed in the Results and Discussion (Pupil Participants) chapter.

7.7 'Scenarios'

7.7.1 Introduction

The 'Scenarios' task group was designed to identify the potential of providing the TG with the ability to compose a story and enact it using the robotics-based system. This is a play activity that typically developing children engage in, but the TG may not have opportunities to do so. This may be a viable method for the TG to have such a play experience.

This activity brought together the robot manoeuvring skills of the 'Directions' task group and the gripping and haptic feedback aspects of the 'Cubes' task stage. The task required the PPs to apply their knowledge to manoeuvre the robotic arm through a series of stages to complete their story.

These tasks involved a high level of PP autonomy i.e. the PP would perform all of the individual robotic arm movements, but with some assistance from the system for particularly complex processes such as positioning of the gripper for gripping stages.

This task group involved the haptic device. Haptic feedback was provided during the gripping stages of the task.

'Scenarios' was comprised of two separate sessions for PP1, but only one for PP2.

The purpose of the 'Scenarios' task group was to engage the PP in story creation and physical enactment ("bringing their story to life"). This task group involved elements of storytelling (Adams et al. 2008) and play and, bringing together concepts involving direction, position and gripping.

7.7.2 Materials and methods ('Scenarios')

During the 'Scenarios' task group, the scene contained a toy pirate ship on top of a raised area and two toy characters: a pirate and a crab (see Figure 7.7).

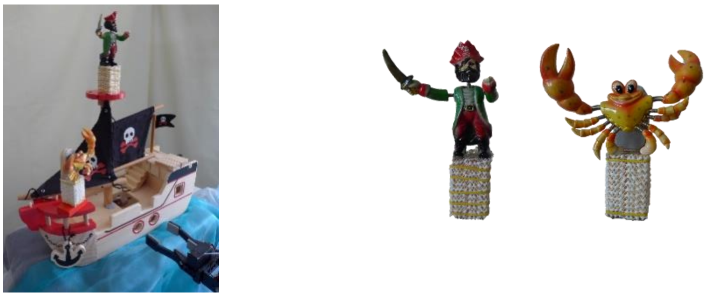


Figure 7.7 The pirate ship and characters

The interface used within the 'Scenarios' task group was based on the 'All controls' interface (see Table 7.5) used in 'Directions'. Some additional cells were introduced. The expanded interface is shown in Figure 7.8 and the functions of the additional cells are described in Table 7.6.

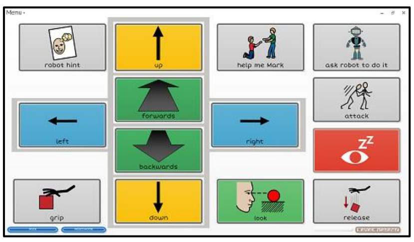


Figure 7.8 Interface controls for 'Scenarios'

Table 7.6 Description of UI controls for 'Scenarios'

				
Asks the system to suggest the next move	Instructs the system to position the gripper ready for gripping the winning character	Instructs the robot to use the 'winning' character to 'attack' the 'losing' character	Closes the gripper	Opens the gripper
The system calculates the next move / optimum route	**Prerequisites / caveats**			
	Dependent on the gripper being within range of the character	The 'winning' character is being held by the gripper and is within range of the 'losing' character	This will only be carried out if a character is within gripping range	If this is done before the end of the story, the PP will need to start afresh

7.7.2.1 Procedure ('Scenarios')

There were two parts to the 'Scenarios' process: 1. Story creation; and 2. Story enactment.

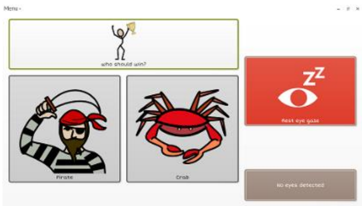
Using the process and interfaces described in Table 7.7 the PP would create their story. From a choice of the pirate and the crab, the PP would choose a 'winning', and by elimination, a 'losing' character. The PP would also choose the locations where each of these characters would be situated upon the pirate ship. The available options were 'bow', 'crow's nest' and 'stern'. Only one character could occupy a particular location on the pirate ship at a time. The investigator would set up the scene for the PP.

This story would then be enacted by the PP using the robotic arm to manipulate the characters, with the outcome being that the 'winning' character is used to 'attack' or knock the 'losing' character from the pirate ship. In greater detail, the two stages are:

1. Story creation

The PP would create their story and the investigator would assist the PP in preparing this story (Table 7.7).

Table 7.7 The process of creating a PP 'story'

Description	**User Interface**	**Live scene**
The PP chooses a winning character. In this example the pirate is chosen.		
The PP chooses a ship location for the winning character. In this example the bow was chosen for the pirate. The investigator places the pirate on the bow.		
The PP chooses a ship location for the losing character (the crab). In this example the crow's nest is chosen. The investigator places the crab on the crow's nest. **Note**: the bow is not available as it is already occupied by the pirate.		
A symbol is attached below the display to remind the PP of the winning character in their story*.		

* This idea was suggested by LSA 1 during a session.

2. Story enactment

Once the PP had created their story, the investigator and PP would progress through the following stages to enact the story:

(1) **Configuration:** The investigator would configure the controlling software for the PP's story.

(2) **Read story aloud:** The investigator would then instruct the controlling software to read out the PP's story. This would be of the syntax:

"The <winning character> on the <winning character's location> will attack the <losing character> on the <losing character's location>"

(3) **Move towards winning character:** The PP would then begin instructing the system to move the gripper near to the winning character.

(4) **Gripping the winning character:** Once near the winning character, the system would provide an auditory prompt for the PP to instruct the system to carry out positioning ready for the gripping part.
(5) **Move towards losing character:** The PP would guide the gripper towards the losing character.
(6) **Attacking the losing character:** Once the gripper was in close proximity to the losing character, the system would provide an auditory prompt for the PP to instruct the system to carry out an attack.
(7) **Attack:** The PP would then issue the attack command and the system would perform this. Once complete the 'winning' character takes the 'losing' character's location.
(8) The arm returns back to the starting position.

Additional Notes

- The PP could ask the investigator or the robotic system for advice about their next move.
- Once the PP was near the next objective, for example gripping the winning character, the final positioning and gripping was assisted by the system (because it is difficult to do manually).
- When the robotic arm was gripping a character, the PP would receive a haptic sensation from the haptic device attached to their chosen hand.

The results are presented and discussed in the Results and Discussion (Pupil Participants) chapter.

7.8 End of Chapter Summary

An intervention was created and used with the two PPs of this study, in which they controlled a robotics-based system to carry out tasks in three groups: 'Cubes', 'Directions' and 'Scenarios'. The purpose was to reveal and build upon the knowledge and abilities of the TG in the context under investigation.

Aspects of the intervention were trialled with the SPs, the results of which are presented and described in the next chapter. Following these trials, the intervention was used with the PP's. The results for the PPs are presented and described in Results and Discussion (Pupil Participants) chapter.

Chapter 8 Results and discussion (Staff Participants)

8.1 Introduction

Trials were conducted with staff participants (SPs) from VEC to pilot aspects of the assessments and intervention. This helped to evaluate the techniques used and to shape the final PP trials. The following elements were tested: physical assessment; haptic prototypes; haptic assessment; intervention usability and workload; test administration procedures; communication approach. The captured feedback represented advice from subject specialist staff, which highlighted issues and identified areas for improvement. This process forms part of the 'Proxy UCD' approach described earlier.

The trials were conducted over two rounds, which are described in detail below.

The 'cognitive' assessments followed a different approach: they were developed, trialled and administered in collaboration with a team of SaLTs and are described in the Assessment Design and Administration chapter.

8.2 Round 1: Outcomes from staff participant trials

The first round covered: the physical touch assessment; evaluation of the full range of nine haptic prototypes narrowing to those thought to be most appropriate and then further narrowing to identify a single suitable prototype for use with the PPs; evaluation of the haptic assessment.

8.2.1 Staff Participant evaluation of the physical touch assessment

The physical touch assessment (described in the Assessment Design and Administration chapter) was trialled with SPs, the purpose being to evaluate the assessment and to identify any anomalies in the design or administration procedure.

Three pairs of SPs evaluated the procedure with one acting as the 'pupil', the other as the communication partner (observer and assistant too). The researcher would, in turn, touch the 'pupil's' left, right, neither and both of their hands – first with the 'pupil's' hands visible and then with them hidden from their view. For this trial, only one repetition of each of the four permutations was performed for the visible and hidden conditions (see Appendix C - Figure C.1). The touch would involve a single stroke of their palm in the direction of wrist to fingertips. The 'pupil' would be asked to indicate what they thought the researcher had done.

The three 'pupil' SPs all scored 100% correct answers in both the 'hands visible' and 'hands hidden' conditions.

SPs completed a questionnaire (see Appendix C - Figure C.2). The results of this questionnaire indicated that changes should be made to the procedure: 1) to reduce the researcher's visible paperwork; 2) to augment verbal explanations with symbol cards (see Appendix D); 3) rest periods should be included in the assessment and some aspects should be split over two sessions; 4) help would be required with keeping PPs' hands still; 5) an issue was identified with the equipment used to screen the PPs' hands, which was later rectified with a longer pole.

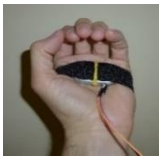
These comments were all addressed in the final version of the physical touch assessment.

8.2.2 Staff participant evaluation of the haptic prototypes

A range of hand-based haptic prototypes were developed (see Table 8.1). Different design approaches were used: 1). Palm-based, 2). Grip/clench-based, 3). Whole hand-based and 4). Digit-based. In total, nine prototypes were created using various materials. All prototypes delivered haptic sensations using the vibrotactile method i.e. vibration.

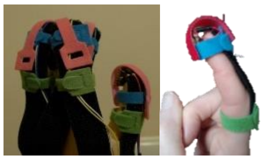
SPs trialled each of the nine haptic prototypes and evaluated them according to such aspects as sensation, fit and suitability for the TG. The SPs were asked to indicate which of the prototypes they considered would be the most appropriate for use with the TG.

Table 8.1 Haptic feedback prototypes

1. Palm-based approaches		
1. Tennis ball	*2. Foam ball*	*7. 'Pebble'*
		

2. Grip/clench-based approaches	
3. 'Soft' roller	*4. Foam roller*
	

3. Whole hand-based approaches	
5. 'Catcher'	*6. Silicone*
	

4. Digit-based approaches	
8. Digit and thumb tips	*9. All digit tips*
	

The SPs' evaluation of the haptic prototypes was important in uncovering the relative strengths and weaknesses of the devices, and capturing comments relating to the various design approaches, as well as identifying the most appropriate prototype(s) for use with the TG.

The SPs were asked to trial each of the nine haptic prototypes and complete a form after each trial (see Appendix E). A collated version of the results from the completed forms for each prototype can be seen in Appendix E - Table E.1.

These sessions unearthed a range of factors that needed to be considered when designing haptic devices for the TG, including: 1) **Fit and fixings**: ease of donning/doffing, secure attachment, comfort, adjustment, degree of contact with palms and fingers; 2) **Materials**: texture, firmness/flexibility/elasticity (important considerations for involuntary movement and spasticity); 3) **Haptic sensation**: location, strength/intensity, transfer to other areas including the straps, allergies; 4) **Hygiene/infection control**: ease of cleaning; 5) **Noise level**: noise from the vibration might add to the multisensory experience or be distracting for PPs.

Some SPs reported a ‘tickling’ sensation from some of the prototypes. One SP felt an uncomfortable sensation in scar tissue – this is of relevance for the TG who may have such tissue due to injuries or operations. Some SPs reported a residual sensation for a time after removing the prototype.

Certain prototypes were found to have a long set-up period, and were quite invasive and obtrusive, involving many wires and attachments.

Following the trials of all nine prototypes, the SPs were asked to indicate three that they considered to be the most suitable for the TG (in no particular order of preference). The results (see Figure 8.1) show that prototypes 7 and 9 were chosen most frequently (4 times each) (see Table 8.2).

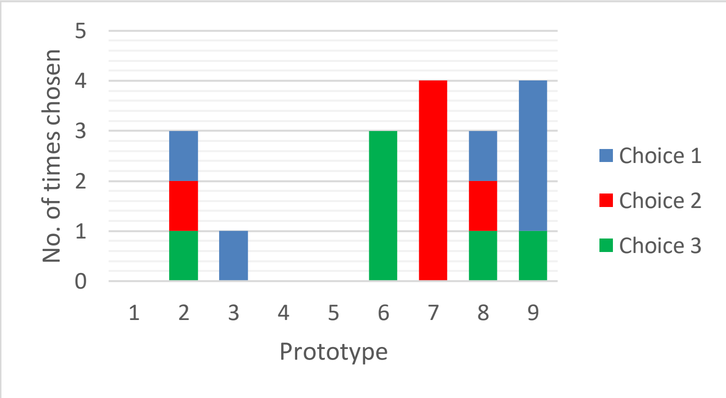
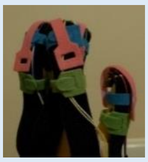


Figure 8.1 Haptic prototypes – number of times chosen by SPs

Table 8.2 Most frequently chosen haptic prototypes by SPs

Prototype 7	Prototype 9
	

These findings helped to identify the most suitable characteristics of haptic prototypes for use with the TG, which then helped to further narrow and focus the development stage.

As prototypes 7 and 9 were most frequently chosen by the SPs, these were used to test the haptic assessment, which is discussed in the next section.

8.2.3 SP evaluation of the haptic assessment and prototypes 7 and 9

Two versions of the haptic assessment were carried out with the SPs, one with palm-based haptic prototype 7 and the other with digit-based prototype 9 (see Table 8.2).

Prototype 7 version of the haptic assessment

Two identical instances of prototype 7 were used, one attached to each of the SP's hands. The haptic assessment was similar in format to the physical assessment. With the SP's hands hidden, haptic sensations were sent to the SP's hands. See Appendix F - Figure F.1 for the answer recording sheet.

Prototype 9 version of the haptic assessment

Prototype 9 consisted of five identical individual digit-worn devices, one attached to each of the SP's digits on their dominant hand. Haptic sensations were delivered to individual digits. The hand was not hidden from the SP's view. See Appendix F - Figure F.2 for the answer recording sheet.

This stage was considered important to investigate: whether 'able-bodied' individuals could accurately locate the source of the haptic sensations; to explore the practicalities of using each prototype in assessments and to decide whether to use either prototype 7 or 9 with the PPs during the haptic assessment and intervention. This stage was also important as it enabled practice of the assessment procedure.

All SPs scored 100% correct answers for both versions of the haptic assessment (see Appendix F - Table F.1 and Table F.2).

Overall, prototype 7 appeared to be the most suitable for use with the PPs. The relative benefits of prototype 7 compared to 9 were:

1) The self-contained, compact design, with only a single attachment strap and control wire meant that prototype 7 was much easier and quicker to don/doff with both those who had contractures or involuntary movement; 2) It was easy to clean and therefore hygienic.

The main disadvantage of prototype 7 was that the sensation was mainly limited to the palm of the hand, unless the PP's fingers made contact with it. However, based on the SPs' feedback, it was considered that a whole hand experience may have provided too much stimulation.

This stage demonstrated that prototype 7 would be the most suitable and practical for use with the TG and so this was the prototype that went on to be developed further and then used with the PPs. The results from this stage led to prototype 7 being developed into a high fidelity prototype ready for use with the PPs in the haptic assessment and the intervention.

8.3 Round 2: Outcomes from staff participant trials

The second round involved the SPs: 1) Trialling various haptic behaviours with the haptic prototype selected in round 1; 2) Trialling and evaluating elements of the intervention.

8.3.1 Staff participant evaluation of haptic prototype behaviours

The haptic prototype selected during Round 1 (number 7) was trialled with SPs, using a range of start and stop behaviours and vibration motor spin speeds, to determine the most appropriate settings for use with the TG. This process was important for identifying suitable haptic behaviours for use with the TG i.e. to avoid startling them or delivering uncomfortable sensations. See Appendix G for the full results.

The vibration motor spin speed most frequently chosen by the SPs was 175. The most chosen start and stop behaviours for the left hand were 'fade-in, fade-out' (times chosen = 4), closely followed by 'fade-in, immediate stop' (times chosen = 3). The most chosen start and stop behaviours for the right hand were 'fade-in, immediate stop' (times chosen = 4), closely followed by 'fade-in, fade-out' (times chosen = 3).

The SP's also completed a questionnaire (see Appendix G - Figure G.1).

Some SPs reported that they did not like the feeling of vibration but one pointed out that lots of pupils do. However, some pupils may be sensitive to the sensation. One SP experienced a residual sensation for some time afterwards. SP 14 noted that a 'stronger' (faster) spin speed seemed 'smoother'.

The most frequently SP recommended spin speed of 175 was used during the trials with the PPs.

The start and stop behaviours used with the PPs were 'fade in, fade out' which were selected to avoid any startling which may have been caused by an abrupt start or stop of the vibration sensation.

This stage highlighted the need to be aware that some PPs may be sensitive to the haptic sensation and that this should be monitored.

8.3.2 Staff participant evaluation of the intervention stages

SPs trialled sections of each of the three main stages of the intervention: 1) 'Cubes'; 2) 'Directions' and 3) 'Scenarios' (see Intervention Design and Administration chapter). This required the SPs to use the robotics-based system and haptic prototypes to complete a series of tasks. This stage was performed to identify potential problem areas and to improve the design of the intervention ready for use with the TG.

SPs were also asked to complete NASA-TLX (see Appendix H), System Usability Scale (SUS) (see Appendix J) and feedback forms during these sessions.

This process helped to evaluate the workload placed on the user whilst completing the tasks, and to measure the usability of the system.

The SPs successfully completed all of the tasks that they were allocated.

NASA-TLX: Generally the workload demands were low across the intervention stages, but with higher average levels for both 'Mental Demand' and 'Effort' during the 'Scenarios' stage (for full details see Appendix **I**). A summary is provide in Table 8.3. Ratings were lowest for 'Cubes' and highest for 'Scenarios'.

Table 8.3 SP NASA-TLX ratings for all intervention task groups

			'Cubes'	**'Directions'**	**'Scenarios'**
Q.	**Sub-scale**	**Range**	**1 task Arithmetic mean (n = 6)**	**5 tasks Arithmetic mean (n = 6)**	**1 task Arithmetic mean (n = 7)**
1	***Mental Demand***	0 = Very Low 100 = Very High	27	28	59
2	***Physical Demand***	0 = Very Low 100 = Very High	17	19	30
3	***Temporal Demand***	0 = Very Low 100 = Very High	15	14	29
4	***Performance***	0 = Perfect 100 = Failure	19	18	17
5	***Effort***	0 = Very Low 100 = Very High	18	31	56
6	***Frustration***	0 = Very Low 100 = Very High	15	20	32

System Usability Scale (SUS): Data gathered using the SUS indicated that system usability was rated by the SPs as 'good' overall throughout the intervention trials (for full details see Appendix K). Average ratings were highest for 'Cubes' and lowest for 'Directions'. A summary is provided in Table 8.4

Table 8.4 SP System Usability Scale ratings for all intervention task groups

SP No.	SUS score (Out of 100)		
	'Cubes'	'Directions'	'Scenarios'
14	-	-	-
17	82.5	92.5	90
8	82.5	77.5	85
7	92.5	70	62.5
19	65	62.5	65
27	-	55	52.5
1	87.5	85	80
6	62.5	57.5	47.5
Mean	79	71	72

NOTE: Some of the SPs' SUS and NASA-TLX scores may have been adversely affected by technical issues which occurred with eye gaze units during some sessions. Some SPs may have given higher ratings for some questions due to these issues rather than because of the system use itself.

Most of the SPs considered that the haptic device added value to the experience, although some did not like the sensation. There was a mix of opinions regarding whether accompanying speech synthesis would be of assistance – this would depend upon the particular task and the purpose of including synthesised speech. Some SPs reported finding it difficult to see the robotic arm or cubes clearly. One SP reported that it was useful to have the two different views of the scene. Finally, there were some reports of the haptic sensations not being in correct synchronisation with the gripping and releasing elements.

One SP reported greater awareness of their hand for a while following a session which involved the use of the haptic device. Some SPs found the tasks easier than others. Some perspective issues were reported - one SP suggested that a bird's eye camera view might help. The robotic arm did not always move as the SPs had anticipated. This may have been due, in part, to the arm moving along planes rather than arcs (see Technical Implementation chapter). There were suggestions to make the table 'quieter' to avoid startling the PPs, to colour the gripper to make it more visible, and to combine the camera view with the interface controls.

This stage led to improvements in the robotics-based system and the intervention ready for use by the PPs, including making the robotic arm and cubes more visible by using a white background and placing screening around the rear of the scene. Speech synthesis was used to accompany individual movements performed by the PPs, but not for automated sequences. The table was made 'quieter' by adding noise-dampening material to the surface.

This stage raised awareness that some tasks may place high demands upon certain individuals and that vigilance would be required to ensure that PPs were monitored for signs of stress, and not placed in unduly demanding situations.

8.4 Conclusion – Feeding Outcomes from Staff Participant Trials into Main PP trials

The staff trials were a vital part of the ‘Proxy UCD’ development process.

At the time of the study, there were only three pupils attending VEC who met the inclusion criteria of the study (see Methodology Chapter), only two of whom assented to participate.

With so few participants, it was not possible to form a group of PPs who were solely involved in the development lifecycle and a separate group who were only involved in the assessment and intervention stages of this study. If the PPs had been involved in both the development lifecycle and the assessment and intervention stages, results would have been affected due to the learning effect.

Even if there had been more participants, their communication difficulties and lack of experience in the design process would have made their involvement highly complex (Guha et al. 2008; Hornof 2009).

This meant that a true User Centred Design (UCD) approach could not be used. In view of this, an alternative approach was adopted involving those who work directly with pupils at the school. These staff participants (SPs) are qualified and experienced in working with those who have disabilities and, therefore, have a good understanding of their physical and cognitive needs and abilities. This approach was referred to in this study as ‘proxy UCD’ i.e. SPs were involved in the development lifecycle to offer their perspective on the requirements of the TG, to represent the TG and inform the design on their behalf.

The SPs involved were from a variety of different professions including education and therapy, bringing a multi-disciplinary team and holistic view to the process.

Important usability aspects were discovered through the above process which could have presented difficulties for the PPs had they not been identified. These included: technical issues; scene visibility; and reduction of noise by making the table ‘quieter’.

The outcomes from this stage fed directly into the full PP trials, which are described in the next chapter.

Chapter 9 Results and Discussion (Pupil Participants)

9.1 Introduction

Following the staff participant trials, which were designed to refine the techniques and delivery of the assessments and intervention, a full trial was conducted with the two pupil participants (PPs). This chapter presents, analyses and discusses the results first of the cognitive and physical assessments and then of the intervention.

The delivery pattern was a baseline assessment, followed by the intervention, followed by a final outcomes assessment. The assessments were split into categories of ‘cognitive’ and ‘physical’. The cognitive assessments used static image-based and video-based approaches, while the physical assessment used physical touch and haptic sensations. The results of the baseline and outcomes assessments were then compared to measure the effect of the intervention.

The results indicated that PP1 was operating at near ceiling ability, which was unexpected and helped to reveal the extent of his understanding of the concepts under investigation. The results also indicated that the cognitive assessment interface techniques did not work well for PP2, who appeared to exhibit side-preference. Both PPs demonstrated good levels of knowledge and abilities during the intervention.

9.2 Cognitive assessments (static image-based and video-based)

The collective term used for the assessments in this section was ‘cognitive’ assessments. This was used to differentiate them from the physical assessments. A more precise term for these assessments is ‘spoken language comprehension assessments’. The term ‘cognitive’ will be used for brevity.

The main aim of the cognitive assessments was to identify the PPs’ knowledge of concepts relevant to the focus of this research (i.e. temporal, spatial and movement), and to see if, and how, this may change as a result of the intervention. The new methods were developed as a result of a lack of appropriate assessment techniques for the TG, which was identified through a review of the literature (see Literature Review chapter).

Two cognitive assessments were created and used with the PPs: a) static image-based and b) video-based. The static image-based assessment was performed first, followed by the video-based assessment.

The results appear to indicate that both of these assessment methods were well suited to PP1, but not to PP2. PP1 scored near ceiling across all of the cognitive assessments, achieving higher results than anticipated. His scores at baseline and outcomes were identical.

As can be seen in Table 9.4, in contrast to PP1, PP2's cognitive assessment scores were low. Some improvement was seen between baseline and outcomes for the static image-based assessment, but for the video-based assessment, PP2's scores declined.

The key results are summarised in the tables below. Details of the static image-based assessments can be found in the Assessment Design and Administration chapter and the full results are shown in Appendix M.

The format for the Cognitive assessments is to present the results for PP1 followed by a discussion of the results and then the same format for PP2.

9.2.1 Cognitive Assessments: PP1

The results for PP1's (cognitive) static image-based and video-based assessments are shown in Table 9.1 (baseline and outcomes).

Table 9.1 PP1: Results of cognitive assessments

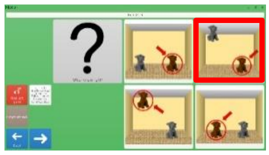
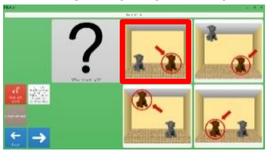
Assessment		**Baseline**	**Outcomes**	**Totals**
Static image-based	**Practice**	3 / 3 (100%)	3 / 3 (100%)	6 / 6 (100%)
	Main Assessment	15 / 17 (88%)	15 / 17 (88%)	30 / 34 (88%)
	Total	18 / 20 (90%)	18 / 20 (90%)	36 / 40 (90%)
Video-based	**Main Assessment**	6 / 8 (75%)	6 / 8 (75%)	12 / 16 (75%)
				48 / 56 (86%)

As can be seen in Table 9.1, PP1's scores were high (and identical) for both the baseline and outcomes assessments (Static image-based: Practice 100% and Assessment 88%; Video-based: 75%). PP1 gave only eight incorrect answers out of a total of 56 questions.

9.2.1.1 PP1: Static image-based assessment

Table 9.2 shows PP1's incorrect answers for the static image-based assessment.

Table 9.2 PP1: Results of the static image-based assessment: Incorrectly answered questions

Question (of 17)	Correct Answer	PP1's (incorrect) answers	
		Baseline	**Outcomes**
Q2. Which one is above?	Above (Bottom-Right) 	In (Bottom-Left) 	N/A (Correct)
Q4. Which one is left?	Left (Bottom-Right) 	N/A (Correct)	Lower (Top-Right) 
Q8. Which one is right?	Right (Top-Left) 	Lower (Top-Right) 	Left (Bottom-Right) 

PP1 answered only four questions incorrectly out of a total of 34 across both (static image-based) assessments. The incorrect answers shown in Table 9.2 were:

Q2. Which one is above? *(Baseline only)*: It is not known why PP1 answered Q2 incorrectly in the baseline assessment. He provided the correct answer in the outcomes assessment.

Q4. Which one is left? (***Outcomes only):*** All of the answer cells for Q4 contained dogs on the left side which may have created ambiguity and confusion for PP1.

Q8. Which one is right? *(Baseline and Outcomes)*: This could be attributed to ambiguity within the question - there is a dog positioned on the right in all of the possible answer cells (see Table 9.2).

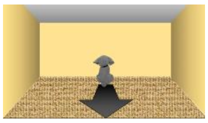
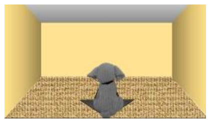
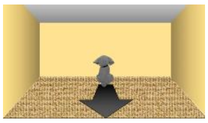
In total, three of PP1's incorrect answers involved the 'dog, circle and arrow' format of questions, possibly indicating a problem with the design of these questions. However, PP1 did exhibit some difficulties with left and right during the intervention, so the cause of the incorrect answers to Q4 and Q8 may not be entirely due to ambiguity within the questions.

9.2.1.2 PP1: Video-based assessment

Table 9.3 shows PP1's incorrect answers for the video-based assessment. PP1's only incorrect answers in both the baseline and outcomes video-based assessments involved the concepts of forwards (Q1. 'Which one is moving forwards?') and backwards (Q2. 'Which one is moving backwards?'), confusing the one with the other.

Table 9.3 depicts the start and end frames of the video clips used to represent the concepts of ‘Moving Forwards’ and ‘Moving Backwards’. In the videos, the dog glides along the floor in the direction of the arrow with its back facing towards the viewer, steadily reducing or growing in size to simulate perspective.

Table 9.3 PP1: Results of the video-based assessment: Incorrectly answered questions

Question (of 17)	Correct Answer		PP1’s (incorrect) answers Baseline and Outcomes	
	Moving forwards (Bottom-Left)		**Moving backwards (Top-Right)**	
Q1. Which one is moving forwards	Start 	Finish 	Start 	Finish 
	Moving backwards (Top-Right)		**Moving forwards (Bottom-Left)**	
Q2. Which one is moving backwards	Start 	Finish 	Start 	Finish 

Possible explanations for PP1’s incorrect answers may be:

(1) **Understanding:** PP1 may have had an incorrectly formed understanding of the concepts of forwards and backwards, or may have perceived the dog moving forwards as the dog moving ‘backwards’ away from him, and the dog moving backwards as the dog moving forwards towards him. One of the SaLTs expressed similar views during the (cognitive assessment) staff trials. Future work could consider how best to resolve this, possibly by presenting a more elevated view.

(2) **Life experiences:** PP1’s life experiences of being moved forwards may be different to the norm. Rather than perceiving himself as moving forwards through the world, he may perceive himself as being stationary and that the world moves backwards (and similar for the concept of moving backwards).

(3) **Frame of reference:** PP1 may have difficulty with frame of reference or perception issues.

(4) **Assessment representation:** PP1 may have understood the concepts but could not relate them to the videos. For example, the arrows were intended to assist with the comprehension of the concepts, but arrows are an abstract representation of direction and may not be understood by all. For those who do understand arrows, it is possible that the ‘forwards’ and ‘backwards’ arrows could be perceived as representing ‘up’ and ‘down’ instead.

9.2.2 Cognitive Assessments: PP2

The results for PP2’s (cognitive) static image-based and video-based assessments are summarised in Table 9.4 (baseline and outcomes).

Table 9.4 PP2: Results of cognitive assessments

Assessment		Baseline	Outcomes	Totals
Static image-based	Practice	2 / 3 (66%)	3 / 3 (100%)	5 / 6 (83%)
	Main Assessment	4 / 17 (24%)	7 / 17 (41%)	11 / 34 (32%)
	Total	6 / 20 (30%)	10 / 20 (50%)	16 / 40 (40%)
Video-based	Main Assessment	4 / 8 (50%)	3 / 8 (38%)	7 / 16 (44%)
				23 / 56 (41%)

PP2's main assessment results were low during both stages with scores ranging between 24% and 50% (seeTable 9.4). As PP2 gave so many incorrect answers throughout all of the cognitive assessments, instead of discussing possible reasons for each of these, it may be useful to discuss PP2's answering behaviour.

Only incorrect PP answers will be discussed here. See Appendix M and Appendix N for full results.

9.2.2.1 PP2: Static image-based assessment

PP2 scored below chance (24%) in the baseline static image-based assessment. This rose to 41% in the outcomes assessment.

The SaLT who carried out the static image-based assessment with PP2 commented that PP2 appeared to be 'perseverating' during the assessment. Analysis of the results indicates some evidence to support this conjecture. The answering patterns of PP2's static image-based assessment results are shown in Table 9.5 and Figure 9.1.

Table 9.5 PP2: Results of static image-based assessment - analysis of answering patterns

Cell location	Correct Answer	PP2			
		Baseline		Outcomes	
		Times chosen	Correct	Times chosen	Correct
Top-Left	5	**12**	3	3	2
Top-Right	4	1	0	1	0
Bottom-Left	5	4	1	**12**	5
Bottom-Right	3	0	0	1	0

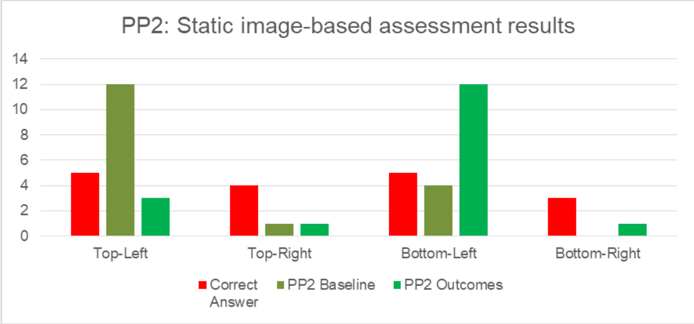


Figure 9.1 PP2: Results of static image-based assessment results (Side-preference)

PP2 appeared to have a tendency towards answer cells on the left side of the grid of four answer cells, particularly the top-left during the baseline assessment and the bottom-left during the outcomes assessment. During the baseline PP2 chose the top-left position 12 out of a possible 17 times (71%) and during the outcomes chose the bottom-left position 12 out of a possible 17 times (71%). In total 24 out of a possible 34 (71%) of PP2's answers were chosen from the left side (Table 9.5 and Figure 9.1).

9.2.2.2 PP2: Video-based assessment

The answering patterns of PP2's video-based assessment results are shown in Table 9.6 and Figure 9.2.

Table 9.6 PP2: Video-based assessment - Side preference issues – left side

Baseline				**Outcomes**			
Cell position	**Times chosen**	**%**	**Correct**	**Cell position**	**Times chosen**	**%**	**Correct**
Top-Left	3	37.5	1	**Top-Left**	4	50	1
Bottom-Left	3	37.5	1	**Bottom-Left**	2	25	1
Total	6/8	75	2 / 6	**Total**	6/8	75	2 / 6

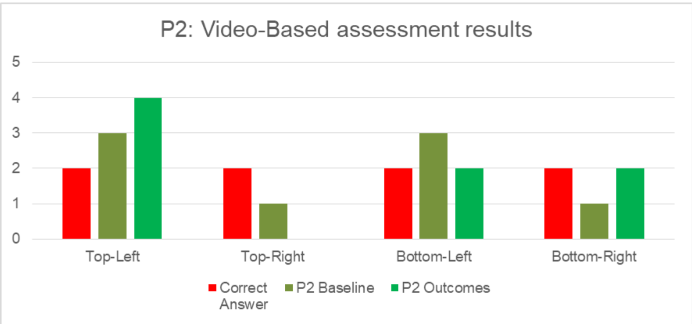


Figure 9.2 PP2: Video-based assessment - Side preference issues – left side

PP2's scores decreased marginally between the baseline (4/8) and the outcomes (3/8) assessments.

Consistent with PP2's behaviour during the static image-based assessment, PP2 again exhibited a degree of side-preference, favouring cells positioned on the left. Table 9.6 shows that 75% of PP2's answers were selected from the left sided cells of the group of four answer cells in both the baseline and outcomes assessments.

Throughout the cognitive assessments PP2 showed a tendency to choose cells positioned on the left side of the grid of four answer cells (Table 9.5, Table 9.6 and Figure 9.2). After the assessments had been conducted, the SaLT revealed that this behaviour was consistent with previous assessments that she had carried out with PP2.

Side-preference issues may have prevented the cognitive assessments from accurately capturing PP2's level of knowledge. It appears, therefore, that these forms of assessment are not always the most appropriate method for ascertaining someone's knowledge. In PP2's case, his performance during the intervention stage may provide a more accurate picture.

9.3 Physical assessments (Physical touch and haptic feedback sensations)

The physical assessments consisted of: a) the physical touch assessment and b) the haptic sensations assessment. These were carried out with the PPs both before (baseline) and after (outcomes) the intervention stage. The results of the assessments are presented and discussed in this section. See Appendix O for the full results.

9.3.1 Physical Assessments: PP1

Table 9.7 shows a summary of the physical assessment scores for PP1 for both baseline and outcomes.

Table 9.7 PP1: Results of physical assessments (Summary)

	Physical touch	**Haptic sensations**	**Totals**
Baseline	20 / 20 (100%)	20 / 20 (100%)	40 / 40 (100%)
Outcomes	20 / 20 (100%)	19 / 20 (95%)	39 / 40 (98%)

PP1 scored at or near ceiling in all of the physical assessments. It is therefore not possible to measure progression between baseline and outcomes.

PP1 appeared to have no obvious issues with detecting the presence or absence of physical touch or haptic sensations in the underside of his hands. Greater focus on specific areas of the hand would be needed to fully understand PP1's ability to discriminate touch and haptic sensations in all parts of his hands.

PP1 achieved a perfect score in both of the baseline assessments, and only made one error in the haptic sensations outcomes assessment. The incorrect answer given during the outcomes haptic assessment may have been due to the speed with which PP1 completed the assessment. He seemed to be viewing it as a challenge to see how fast he could complete it. Future work could examine how this may be taken into account, for example by offering some other 'reward' mechanism that encourages accuracy rather than speed.

9.3.2 Physical Assessments: PP2

Table 9.8 shows a summary of the physical assessment scores for PP2 for both baseline and outcomes.

Table 9.8 PP2: Physical assessment results (Summary)

	Physical touch	**Haptic sensations**	**Totals**	**Notes**
Baseline	7 / 20 (35%)	14 / 20 (70%)	21 / 40 (53%)	Answers obtained using an E-tran frame
Outcomes	14 / 20 (70%)	20 / 20 (100%)	34 / 40 (85%)	Answers obtained using eye pointing

PP2 scored well in all but the baseline physical touch assessment, with possible explanations for this given below. PP2 showed a marked improvement for the haptic sensations assessments between baseline and outcomes.

PP2's scores were low in the baseline physical touch assessment (7 / 20). This may have been due to difficulties with the method used to obtain PP2's answers (an E-tran frame). It seems that PP2 was not as proficient with this method as was first thought. Following the advice of his SaLT, the physical assessment answering method used in the baseline assessment was abandoned and a different approach used for the rest of the assessments. The new method used was for PP2 to use eye-pointing e.g. looking towards his left hand if that is where he considered that he felt the sensation. This was a more familiar method to the participant and the change may account for a proportion of the increase in score in the outcomes. PP2's scores physical touch scores improved by 100% (from 35% to 70%) between the baseline and the outcomes assessments.

PP2's ability to detect physical touch sensations may also have been affected by the simultaneous sensation of the OT holding his hands causing discrimination problems.

PP2 scored well in the baseline haptic sensations assessment (70%), and achieved a perfect score in the outcomes assessment (see Table 9.8). This was a marked improvement in scores. Both of these assessment scores were higher than those of the physical touch assessments. This suggests that the haptic feedback approach may have been a more suitable method than physical touch for identifying PP2's ability to identify the source of a tactile sensation, although the nature of the sensations is different. PP2's baseline physical touch assessment scores may also have been affected by the unsuitable answering method used at that stage.

The increase in the haptic scores could also be attributed to PP2 becoming more aware of his hands due to the research encouraging the participant to pay more attention to his hands. It could also be attributed to day-to-day variations in his ability and condition.

9.3.3 Comparison of physical versus haptic assessment (Summary)

The haptic assessment was simpler to administer than the physical touch. The haptic devices were fitted quickly and there was no requirement for an OT to hold the PP's hands during the assessment, or to conceal the PP's hands from them. This approach also delivered a more consistent sensation to the hands of the PPs compared to physical touch.

There was little difference between PP1's physical touch and haptic assessment scores. All of PP1's physical assessment scores were at or near 100% in both the baseline and outcomes assessments. PP1's physical assessment scores seem to indicate that PP1 was able to accurately detect the presence or absence of sensations in the underside of his hands be they physical, or artificial.

PP2's assessment scores were higher for the haptic assessment when compared with the physical. His overall lower scores in the physical touch assessments could have been due to the simultaneous sensation of the OT holding his hands causing discrimination problems. PP2's baseline physical touch assessment scores may also have been affected by the unsuitable answering method used at that stage.

The use of haptic feedback devices could provide a simpler, less invasive method of assessing such individuals' ability to identify the source of tactile sensations.

9.4 Intervention - Tasks

The assessments described in Sections 9.2 and 9.3 were conducted before and after the intervention. The intervention involved the PPs using the robotics-based system to complete a set of tasks, the results of which are presented and discussed in this section.

The tasks formed three groups, which are described in more detail in the Intervention Design and Administration chapter. The three groups were:

(1) **Cubes**: A group of tasks in which coloured cubes were picked up and dropped into a box. This involved the researcher asking the PP a question, which they would answer using the robotics-based system.
(2) **Directions**: Tasks requiring the PP to demolish structures made of wooden blocks. The PP needed to issue individual commands to move the gripper in three dimensional space.
(3) **Scenarios**: A robot supported story creation and enactment task.

The main difference between group 1 and groups 2 and 3 is that group 1 involved questions with a correct answer, whereas 2 and 3 involved completion of a task using whatever strategy the PP chose to adopt. Haptic feedback was involved in 'Cubes' and 'Scenarios', but not 'Directions'.

After the PP had completed a task, or sometimes a group of tasks, the accompanying member of staff would complete a NASA-TLX form on the PP's behalf (see Appendix H). NASA-TLX forms are usually completed by the individual who is using the system, but in the present study they were completed by an LSA (see Methodology chapter). The LSA would estimate what they perceived the workload demands were for the PPs when completing tasks, based on their knowledge of the PP and the PP's behaviour during the tasks. The forms were completed in this manner because the PPs had limited experience of rating scales, especially fine detailed ones which involve relatively complex language, such as NASA-TLX. The purpose of capturing NASA-TLX data was to identify the workload demands placed upon the PPs and to ensure that the PPs were not being placed under unnecessarily high workloads.

It should be remembered that the purpose of the intervention was see if the TG could understand and use the system and both to examine how the PPs answered or approached the tasks, and also to help them to learn about the concepts under investigation, ideally filling gaps in their knowledge. Therefore, any incorrect answers would be pointed out to the PPs (immediately following a task) and explanations given about the correct answer. The investigator provided brief training sessions throughout. These would consist of asking the PPs to look at their left or right hands, answering questions relating to colour, directional concepts and so on.

The PPs received encouragement during completion of the tasks and were offered, and were able to ask for, assistance if needed.

Finally, after all task groups had been undertaken the questionnaire in Appendix R was completed by the LSAs. The answers given are shown in Appendix R - Table R.1.

The results of the intervention are summarised and discussed in the following sections, with full results available in the appendices.

9.4.1 Intervention: 'Cubes' task group

The first of the three task groups was a set of tasks using three coloured cubes. The 'Cubes' task group consisted of three parts: familiarisation, task set 1 and task set 2. These were conducted over three sessions.

The purpose of the familiarisation session was for the PPs to become acquainted with the environment, use of the system, including moving the robotic arm, and the haptic sensations. The second and third sessions contained the main tasks, which involved picking up cubes and dropping them into a box in different orders depending on the particular question.

'Cubes' was designed to identify and improve the PPs knowledge of the concepts shown in Appendix B (see 'Cubes' in the 'Intervention' section of Table B.1).

A single NASA-TLX form was completed by the accompanying LSA at the end of each of the three sessions for each PP.

In this section, the results for both PPs are presented together for the purposes of brevity and not for direct comparison between PPs. Full results can be found in Appendix P (PP1) and Appendix Q (PP2).

Both PPs completed all of the tasks that they attempted, more than half of which were completed correctly in both cases. Table 9.9 summarises the PPs' scores for all of the 'Cubes' tasks.

Table 9.9 Both PPs: 'Cubes' task scores

	Session No.				
	1	**2**	**3**		
	No. correct/No. attempted			**Total**	**%**
PP1	--	11/14	8/13	19/27	70
PP2	--	7/14	6/6	13/20	65

9.4.1.1 Both PPs: 'Cubes' – Part 1 (familiarisation) session

This was the first session in which the PPs were exposed to the system, the purpose being to introduce them to it. There were no tasks during this session. The researcher used the system giving a demonstration of how it worked. The PP then used the system for themselves, becoming familiar with its use and wearing and experiencing the haptic device. The PPs practiced picking up cubes and putting them into a box.

9.4.1.2 'Cubes' – Parts 2 and 3

These two parts involved the PPs attempting the list of tasks. The results for both of these parts are discussed together as all of the tasks are related i.e. they all concern tasks involving the three coloured cubes.

9.4.1.3 PP1: 'Cubes' 2 and 3

PP1 attempted 27 tasks over the course of 'Cubes' 2 and 3, of which he correctly completed a total of 19 (11/14 and 8/13 respectively) or 70% (see Table 9.9).

There now follows an analysis of PP1's answers with emphasis on those which were 'incorrect'.

Overall: PP1 appeared to have a very good understanding of the colours under investigation. He exhibited some confusion between left and right, and often seemed to forget the subsequent parts of multi-part questions. He also attempted to pick up a cube that had already been put into the box (although there was only one question in total which tested this).

Colour: PP1 appeared to have a good understanding of the colours under investigation with 10/10 for tasks of the format 'Put the <colour> cube in the box', and 6/6 for tasks which involved matching a pointed to coloured cube with an interface cell.

Already in the box (Task 7): PP1 attempted to pick up a cube that was no longer there i.e. it had already been put in the box by him in an earlier task. Possible explanations may be that PP1 did not understand that this was not possible, he may have been complying with the researcher's instructions, or was simply experimenting to see what would happen.

Left and Right (Tasks 10, 11 and 21): PP1, gave incorrect answers for both tasks 10 and 11 which involved the concepts of 'left' and 'right' respectively. PP1 also gave an incorrect answer for task 21 which involved the concepts of 'all' and 'left' (the 'left' component of the question was answered incorrectly). This may indicate that PP1 has some difficulty regarding the positional concepts of left and right. PP1 did not exhibit the same difficulty with the concepts of 'moving left' and 'moving right' in the video-based assessment, scoring 2/2 in both the baseline and outcomes assessments. Interestingly, when asked to look at his left and right hands he would usually answer correctly.

Multi-element (Tasks 24, 25, 29 and 30): PP1 appeared to have some difficulty with tasks involving multiple elements. For example in task 24 'Put the yellow and blue cubes in the box', PP1 omitted the second part of the task, i.e. in this instance failing to put the blue cube in the box. This may have been due to the delay caused by the robotic arm performing the first part of the task. While this was happening, PP1 appeared to forget the second part of the instruction. This may be indicative of a short-term memory impairment.

To address the delay issue, the system could be redesigned to allow both commands to be queued, similar to the 'Play sentences' used in the 'PlayBot' study (Tsotsos et al. 1998), where the system would carry out the first instruction, immediately followed by the second. Alternatively, prompts could be provided as reminders to the PP.

Once prompted by the researcher, PP1 liked to complete the task, correcting his mistakes. This may have inadvertently been beneficial to the development of his understanding of the concept because he carried out the correction, rather than just listening to an explanation of the mistake i.e. 'learning by doing' (Papert 1980).

9.4.1.4 PP2: 'Cubes' 2 and 3

PP2 attempted 20 tasks over the course of 'Cubes' 2 and 3, scoring a total of 13 correct answers (7/14 and 6/6 respectively) or 65% (see Table 9.9). PP2 attempted 'Cubes' tasks 1 to 20, so did not complete the multi-element tasks (24, 25, 29 and 30).

There now follows an analysis of PP2's answers with emphasis on those which were 'incorrect'.

Overall: PP2 appeared to have a very good understanding of the colours under investigation. He exhibited some confusion between left and right. He also attempted to pick up a cube that had already been put into the box (although there was only one question in total which tested this).

All (**Task 1):** PP2 did eventually complete the task, but incorrectly attempted to put the Blue cube in the box a second time, even though it had already been placed in the box.

Already in the box (Task 7): PP2 attempted to pick up a cube that was no longer there i.e. it had already been put in the box by him in an earlier task. Possible explanations may be that PP2 did not understand that this was not possible, he may have been complying with the researcher's instructions or was simply experimenting to see what would happen. PP1 also responded incorrectly in Task 7.

Colour (Tasks 3, 4, 7, 13 and 14): Some confusion regarding colour and spoken language was evident, with PP2 answering five questions incorrectly. Although, in tasks involving pointing and matching based on colour (15-20) PP2 scored 100% (6/6). Tasks 18-20 used the 'mixed' interface (see Intervention Design and Administration chapter Table 7.4 (2)), which meant that the cubes on the interface were not presented in the same order as they appeared in the 'live' scene.

Left and Right (Task 10): Position: PP1 chose the middle cube rather than left-most cube.

The side preference behaviours observed during the cognitive assessments were not observed during 'Cubes' until task 18, just after the interface had been changed. PP2 appeared to become 'stuck' on selecting the 'deactivate/activate eye gaze' cell (17 times in total). **NOTE**: This coincided with him beginning to fatigue and appearing uncomfortable and resulted in 'Cubes' session 3 being cut short. Unfortunately, there was no room in the schedule to complete the remaining tasks of 'Cubes 3'.

Some of PP2's difficulties may have been because his attention was divided between looking at the interface, scene (Encarnação et al. 2016) and listening to the investigator's instructions.

PP2 was observed to smile and vocalise frequently during haptic feedback periods and LSA 1 noted in the Final LSA Questionnaire (see Appendix R – Table R.1) that the PPs appeared to enjoy the haptic sensation.

LSA 1 commented that it would have been useful to have had a 'finished' button on the interface so that the PP could indicate when they had finished a task (rather than the investigator having to ask them). LSA 1 also suggested repeating the task instructions several times.

9.4.1.5 Both PPs: NASA-TLX ratings for 'Cubes' 1

LSA 1 accompanied both PPs to the first session and completed one NASA-TLX form for each PP. The results from these forms are shown in Figure 9.3.

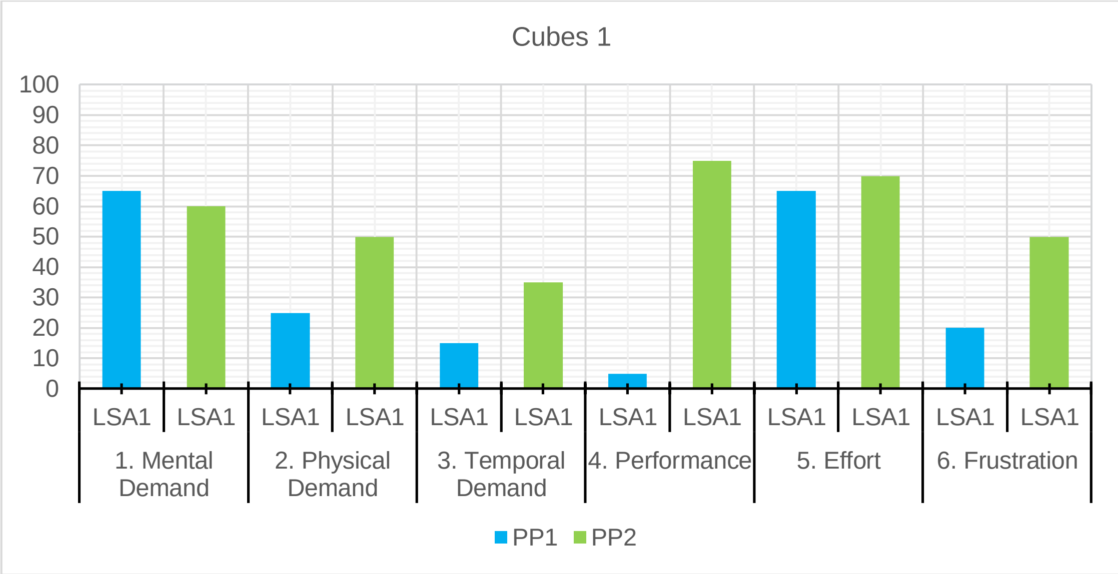


Figure 9.3 Both PPs: 'Cubes' 1 - NASA-TLX form

During this session, LSA 1 rated the NASA-TLX 'Mental demand' and 'Effort' as relatively high (>= 60) for both PPs, but most ratings were below or equal to 50, suggesting a moderate workload level (see Figure 9.3).

There were some technical issues during both PPs' sessions which may have irritated the PPs and increased their tension levels and in turn this may have affected the ratings given by LSA 1.

9.4.1.6 Both PPs: NASA-TLX ratings for 'Cubes' 2

LSA 2 accompanied both PPs to the second session and completed one NASA-TLX form for each PP. The results from these forms are shown in Figure 9.4.

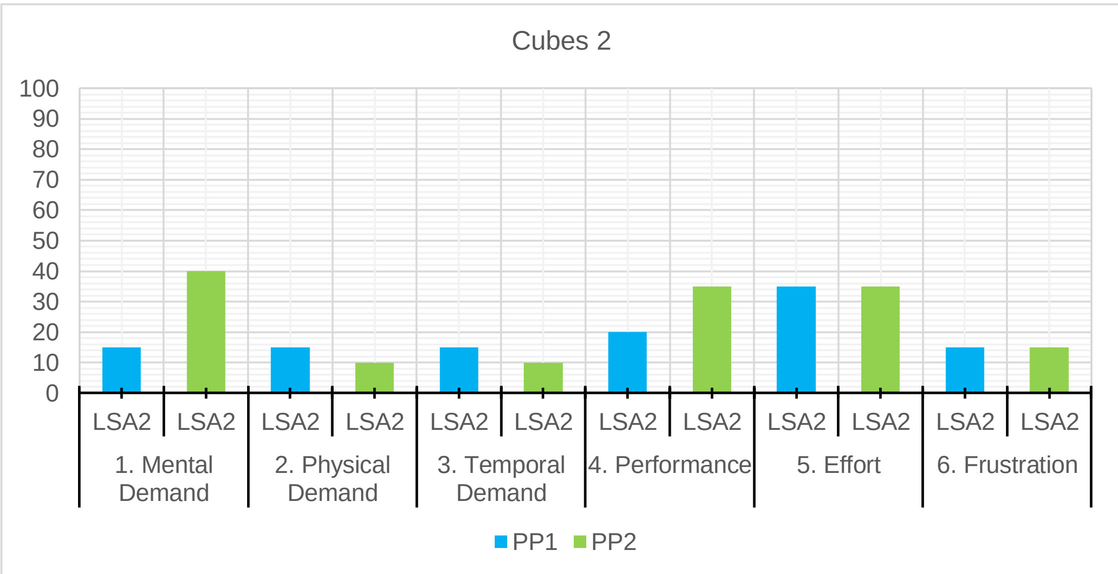


Figure 9.4 Both PPs: 'Cubes' 2 - NASA-TLX form

Overall, the workload ratings provided by LSA 2 for 'Cubes' 2 were lower compared to LSA 1's in 'Cubes' 1 (see Figure 9.4). All ratings were below 50, suggesting a moderate workload level. Possible explanations for the lower ratings might have been that the PPs had had some experience of using the system in the 'familiarisation' task, but it could also be due to differences in LSA rating levels.

LSA 2 did not work with PP1 as frequently as LSA 1 at the time of the sessions, which may have affected the ratings that were given for PP1 – LSA 2's understanding of him may have been less well developed than that of LSA 1.

9.4.1.7 Both PPs: NASA-TLX ratings for 'Cubes' 3

LSA 1 accompanied both PPs to this session and completed one NASA-TLX form for each PP. The results from these forms are shown in Figure 9.5.

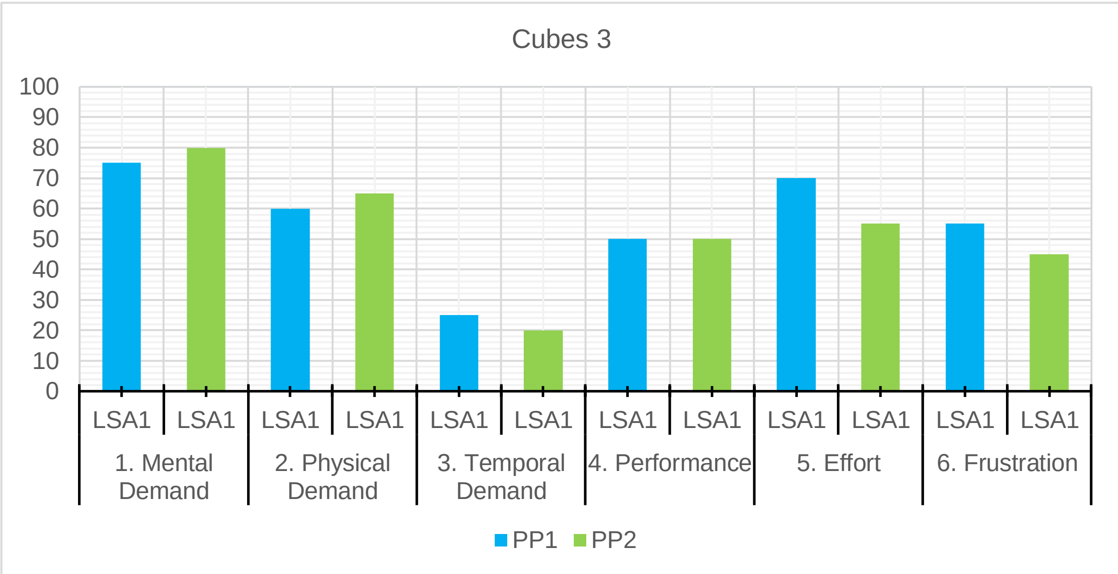


Figure 9.5 Both PPs: 'Cubes' 3 - NASA-TLX form

The ratings were similar to 'Cubes' 1 (also rated by LSA 1) and higher than those during 'Cubes' 2 (rated by LSA 2). The categories of 'Mental demand', 'Physical demand' and 'Effort' were all rated above 50 for both PPs (see Figure 9.5).

Overall, 'Cubes' 3 were the most challenging of the 'Cubes' tasks and so increases were expected. The high ratings given for both PPs for 'Mental demand' and 'Effort' reflect this.

'Mental demand', 'Physical demand' and 'Effort' were all rated highly for PP1 – a possible explanation is that generally he has a lot of involuntary movement and LSA 1 may have perceived that he had to use effort to control the movement while carrying out the task. Note also that PP1 completed the Multi-element Tasks (24, 25, 29 and 30), which PP2 did not.

9.4.1.8 Final summary of ‘Cubes’

Both PPs’ scores in the ‘Cubes’ tasks indicated good levels of knowledge and ability. PP1 displayed some evidence of left-right confusion and difficulty following longer, more complex instructions. PP2 appeared to have some difficulty selecting cubes based on spoken instructions. Both PPs scored full marks for the six pointing and matching tasks (15-20). Both attempted to select a cube that had already been dropped into the box.

There appeared to be NASA-TLX rating differences between LSAs. ‘Mental demand’, ‘Physical demand’ and ‘Effort’ were all rated above 50 by LSA 1.

9.4.2 Intervention: ‘Directions’ (Towers) task group

The second of the three task groups was ‘Directions’. The ‘Directions’ task group involved control of the robotic arm using individual movements and consisted of two parts: ‘feed the giraffe’ and ‘towers’.

‘Feed the giraffe’: No measurements were collected during this stage as its purpose was for the PPs to become familiar with controlling the robotic arm in three dimensions.

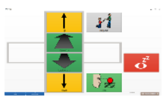
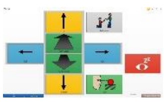
‘Towers’: This involved the PPs manipulating the robotic arm in three dimensions to demolish a variety of structures.

The LSAs were encouraged to keep notes relating to the sessions in a journal from hereon in (see Appendix S). These will be discussed throughout the rest of this chapter where applicable.

Both PPs completed all of the tasks that they attempted. They completed most of the tasks quickly and efficiently, needing little assistance.

The tasks contained increasing levels of complexity as they progressed. In early tasks, only two directional cells were presented at the interface, progressing to four and finally six in the later stages (see Table 9.10).

Table 9.10 Number of available direction interface controls per task

No. of direction controls available at the interface	Interface example	Tasks	NASA-TLX ratings
2		1, 2, 3, 4, 5, 6	All relatively low (<50)
4		7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18	Some TLX factors increased: 10, 16, 14, 17, 18, 12, 19
6		19, 20, 24	Task 24 had some higher ratings

9.4.2.1 Both PPs: 'Directions' (Towers)

In this section the results for both PPs are presented together for comparison, followed by descriptions of both together, and then individually. Finally the NASA-TLX scores are presented and then described.

Please note: A configuration error occurred during PP2's completion of tasks 17, 18, 12, 19, 20 and 24 (the software was incorrectly set to 'Scenario' mode). This error meant that the units of movement were half of what they should have been, requiring PP2 to perform twice the number of moves to complete each task (since the unit of movement was 1 rather than 2).

This error only became apparent after the session and partially accounts for the high number of moves required to complete some tasks, for example task 19, which required 46 movements for PP2 to complete (but he wanted to and did complete it – this is evidenced by LSA 2's comment in their notes: "PP2 showed great determination to complete the task").

The number of moves taken to complete the task is shown in Figure 9.6. This shows the number of moves in which the investigator could complete each task and the number of moves taken by each PP.

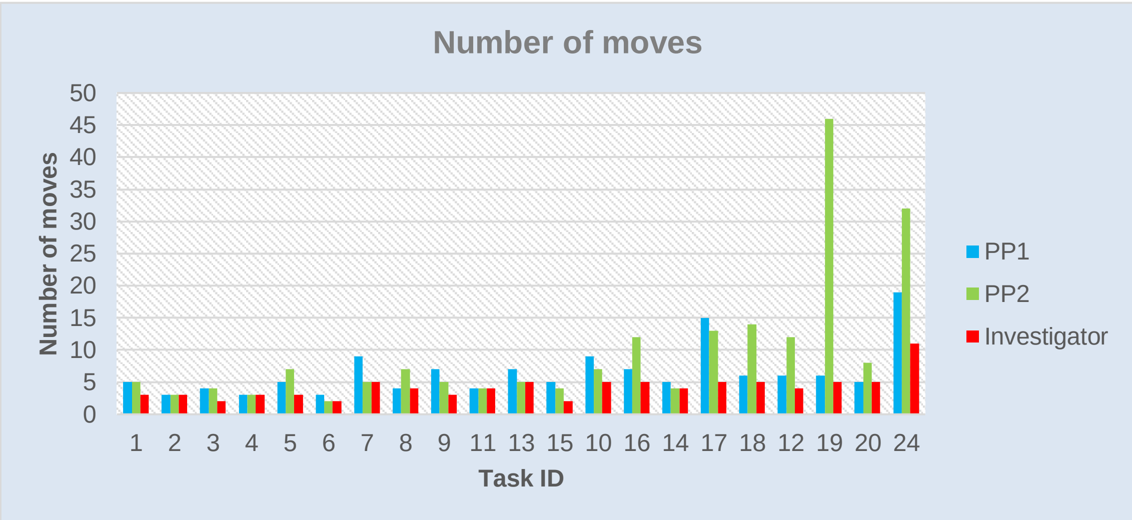


Figure 9.6 PP's number of moves to complete tasks compared with the investigators. Values for PP2 beyond task 17 were affected by a configuration error and are indicative only

Figure 9.7 shows the time taken to complete each task for both PPs. The times taken to successfully complete the tasks were broadly similar for both PPs until task 17, when the configuration error occurred for PP2.

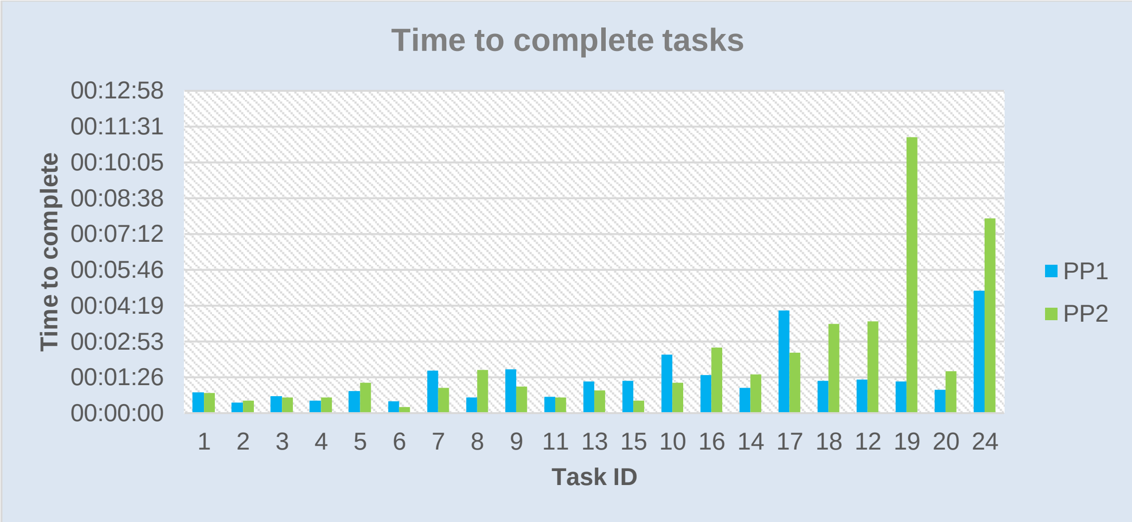


Figure 9.7 Both PPs: Time to complete tasks

Figure 9.8 shows the number of errors made by the PPs during completion of the tasks. In this context, an error was classed as a movement which took the PP further away from the goal rather than closer to it.

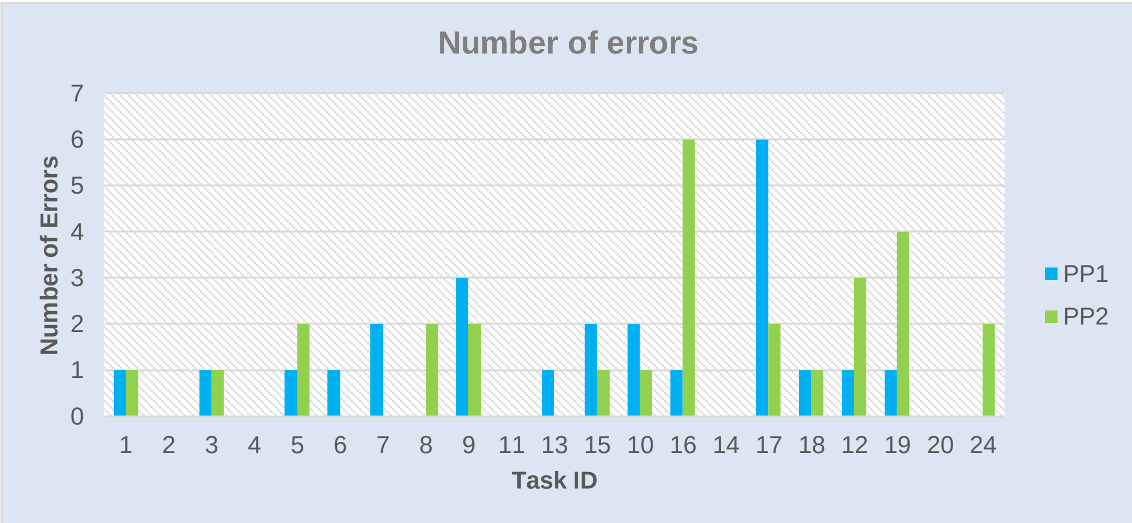


Figure 9.8 Both PPs: Number of errors during tasks

Figure 9.9 shows the amount of time that the PPs spent looking at the live scene after executing a command when there was a live view onscreen.

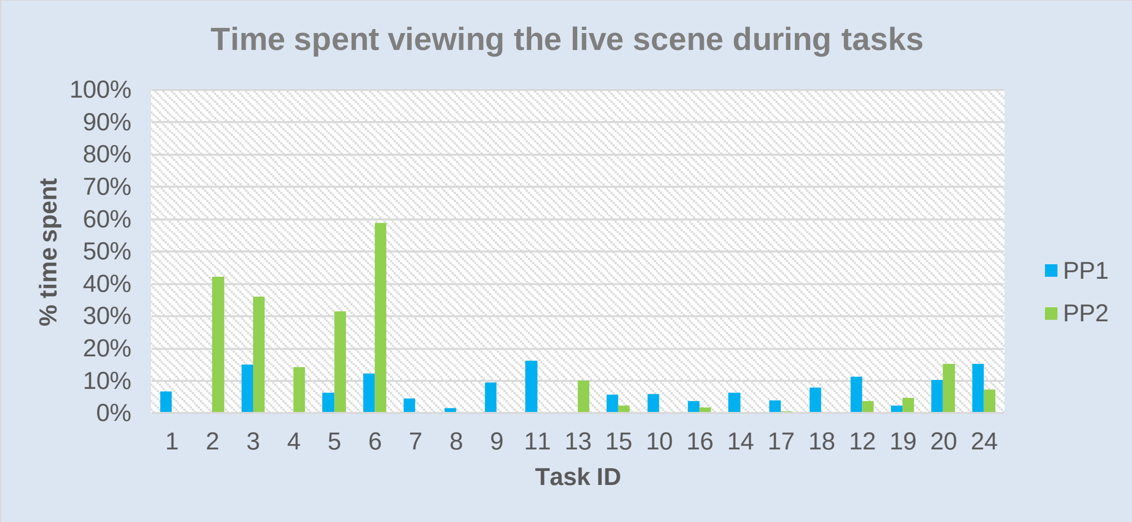


Figure 9.9 Both PPs: Percentage time viewing live scene during 'Directions' tasks

Number of moves taken to complete the tasks: Generally, the number of moves taken by both PPs often matched, or was close to, those achieved by the investigator (see Figure 9.6).

Task 17 took longer for PP1 to complete and the number of errors made increased. Possible explanations for this are provided in section PP1: 'Directions' (Towers).

Task 19 shows an exceptionally high number of moves for PP2. This can in part be attributed to the configuration error noted earlier. Task 24 was a relatively unstructured activity with numerous possible solutions.

Percentage of time viewing live scene: Both PPs spent considerably more time viewing the onscreen video feed compared with the live scene. This may have been because the onscreen view was nearer to them (the live scene was offset diagonally to their right and a greater distance away from them than the screen, which was directly in front of them). It may, therefore, have been more comfortable for the PPs to stay focussed on the screen, thus avoiding having to turn their head. They may have found it more convenient and thought that they could see all that they needed to see onscreen. PP2 spent more time looking at the live scene during earlier tasks, but this reduced later. This may have been due to the increase in complexity of the interface, and the task making it more difficult for him to divide his attention.

This predominantly 'one view' approach may have made some tasks more difficult for the PPs by introducing depth perception issues.

Number of errors made: Overall the number of errors made by the PPs was low, with most moves taking them closer to accomplishing the task.

Errors in their opening move: During seven different tasks (not the same for each PP) both PPs started a task with a move that was in the opposite direction to that required to complete the task. For example, Task 1 required the PPs to move the robotic arm to the left to complete the task, but both PPs started with a move to the right. Upon realising the error the PPs would usually correct this move (with a correct move). It seemed that they may have been uncertain of the required direction and so were 'trialling' a move to see if it was the correct one. They often seemed to understand how to accomplish the task, but not always how to do this with the robotic arm.

Time to complete tasks: The PPs completed many of the tasks in similar times, with the exception of later tasks where the configuration error occurred for PP2 (see Figure 9.7).

9.4.2.2 PP1: 'Directions' (Towers)

PP1 completed many of the tasks in a similar number of moves to the investigator. Task 17 took PP1 substantially longer. This task involved moving the gripper up and left to demolish the structure. As mentioned, PP1 may have some difficulties with left and right. This combined with using predominantly the onscreen view may have made the task more difficult for him.

Opening move observation: In seven of the tasks attempted by PP1 his opening move was opposite to one which moved the gripper nearer to the goal (analysis arrived at from examination of the log files) and LSA 1 also commented in their session notes that, at least in the first 'Directions' task, PP1 was quickly able to work out the correct movements after having selected the wrong one first.

Percentage of time spent viewing the live scene: PP1 spent under one fifth of the time viewing the live scene overall during the 'Directions' tasks.

Key observations identified in LSA 1's session notes (see Appendix S - S.1) were that PP1:

- Got frustrated at times, e.g. when waiting or when he could not "work something out";
- Often forgot things, e.g. while there was a gap or pause in proceedings;
- Gradually became quicker at solving problems, which surprised the LSA;
- Demonstrated excellent problem-solving – LSA commented: "completely amazed – I was unsure if PP1 would be able to work these out";
- Gave up easily, sometimes appearing uncertain of what to do – the LSA did not expect this.

LSA 1's surprise at the problem-solving skills that PP1 demonstrated is similar to that described by Cook et al. (2005) where they refer to teaching staff being surprised by the achievements of children with disabilities when using robots and their abilities being under-estimated.

9.4.2.3 PP2: 'Directions' (Towers)

For PP2, tasks 17, 18, 12, 19, 20 and 24 all had the configuration error noted in 9.4.2.1, requiring PP2 to issue double the number of commands to complete each task. In part, this accounts for the greater number of moves and the time taken for these tasks. This makes comparison of PP2's task scores with the researcher's and PP1's impractical.

Opening move observation: In seven of the tasks attempted by PP1 his opening move was opposite to one which moved the gripper nearer to the goal.

Percentage of time spent viewing the live scene: PP2 spent proportionately more time viewing the live scene early on, but very little in later tasks. This may have been related to an increase in the task complexity increasing PP2's cognitive load and reducing his ability to divide his attention between two different views.

Key observations identified in LSA 1 and LSA 2's session notes (see Appendix S) were that PP2:

- Had a change of mood (from bad to good) and was happy to work when he realised it was "research day" (LSA 1);
- Appeared to enjoy things going wrong (LSA 1 and LSA 2);
- Showed determination, e.g. to complete a task (LSA 1 and LSA 2);
- Was always keen to start and very focussed (LSA 2);
- Demonstrated good and quick problem-solving skills (LSA 2);
- Was good at correcting mistakes (LSA 2);
- Was good at following instructions (LSA 2);
- Found tasks easy (LSA 2);
- Liked being able to watch the towers being built on-screen (LSA 2) – it could be suggested that this strategy might have had the dual benefit of PP2 learning about the construction of the towers by observation (Bandura 1977) and enabling him to have a short period of 'reflection' to solve the problem.

LSA 2 particularly commented about PP2's levels of enjoyment during the tasks, something that Cook et al. (2010) highlight as being important in the design of specialist robots, stating that they should be "appealing".

9.4.2.4 Both PPs: NASA-TLX ratings for 'Directions' (Towers)

Please note: During certain sessions, some NASA-TLX forms were not completed. It was not possible to know which of the completed forms matched with which tasks and so these were removed and redone later by the same LSAs watching videos of the sessions side-by-side (a view of the PP and a view of the live scene). The affected forms can be found in Appendix T. A summary is provided here:

Directions – Towers 1

- PP1: Forms 1-6 LSA 1
- PP2: Forms 1-6 LSA 1

Directions – Towers 2

- PP1: Forms 4, 7, 8, 9, 11, 13, 15 (task 4 was repeated due to an error in configuration when performed in Towers 1) LSA 1
- PP2: Forms 7, 8, 9 LSA 2

Table 9.11 shows the tasks performed in each session and how the NASA-TLX ratings were taken.

Table 9.11 ‘Directions’ tasks per session rated using NASA-TLX by LSA’s - live or from video

‘Towers’ stage	PP1				PP2			
	Date	**Tasks**	**NASA-TLX**	**LSA**	**Date**	**Tasks**	**NASA-TLX**	**LSA**
1	06/06/17	1, 2, 3, (4), 5, 6	Video	1	07/06/17	1, 2, 3, 4, 5, 6	Video	1
2	08/06/17	(4), 7, 8, 9, 11, 13, 15	Video	1	09/06/17	7, 8, 9	Video	2
	12/06/17	10, 16, 14	Live	1	13/06/17	11, 13, 15, 10, 16, 14	Live	2
3	15/06/17	17, 18, 12, 19, 20, 24	Live	1	20/06/17	17, 18, 12, 19, 20, 24	Live	2

Figure 9.10 and Figure 9.11 show the six NASA-TLX factors and the ratings for both PPs. The zones indicated by the numbers 2, 4 and 6 show the number of direction cells available at the interface during those tasks. The blue and green vertical lines and horizontal arrows indicate the tasks where ratings were taken live for PP1 and PP2 respectively.

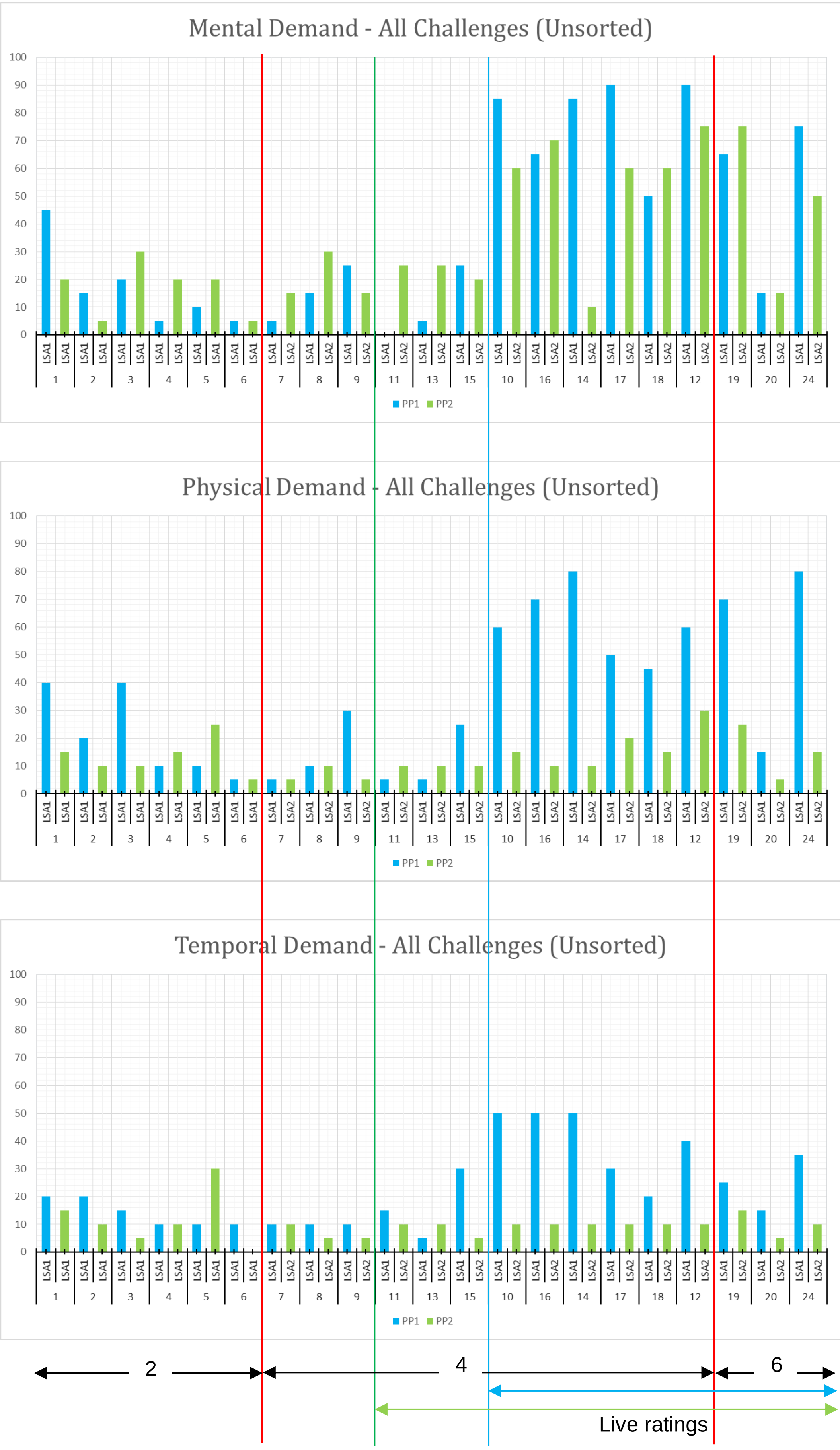


Figure 9.10 'Directions' NASA-TLX ratings – Mental, Physical and Temporal Demand

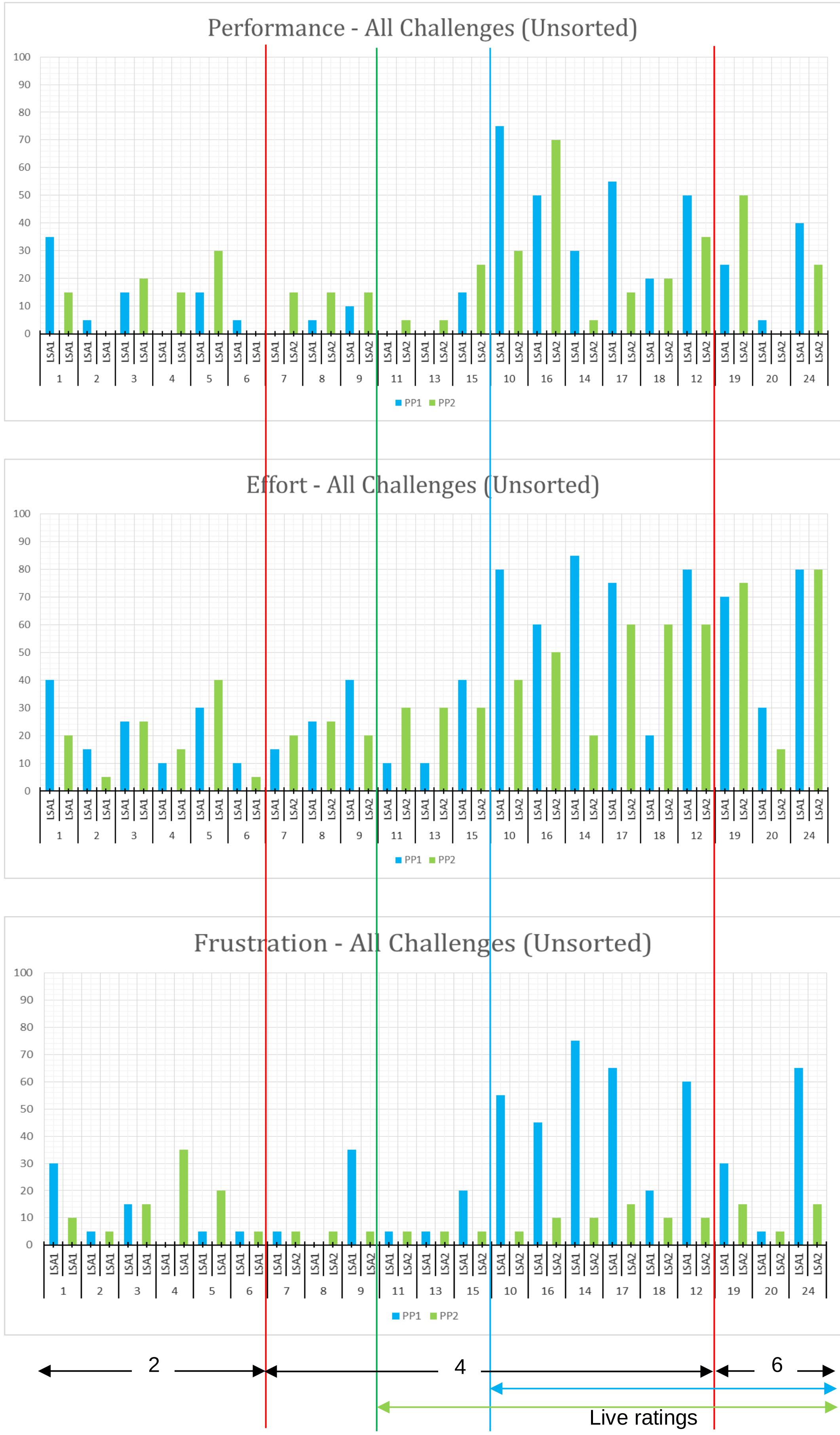


Figure 9.11 'Directions' NASA-TLX ratings - Performance, Effort, Frustration

The expected results were for a small increase in ratings in the NASA-TLX data as the task difficulty increased. The overall purpose of the intervention was to reveal knowledge and ability. In doing so the tasks were designed, as all tasks are, to challenge the participant to discover their limits.

The TLX data should not be viewed in isolation. It was designed to give an indication of task workload rather than task outcome and an indication of the PPs' experience of the process.

During 'Directions' – 'Towers' there were 39 out of a total of 252 NASA-TLX ratings which were higher than 50. Each PP had seven tasks which received one or more NASA-TLX ratings above 50 (see Table 9.12).

Table 9.12 'Directions': NASA-TLX ratings: tasks with ratings > 50

	Task ID		No. of NASA-TLX ratings greater than 50 per task
	PP1	**PP2**	
	10	---	5
	14, 17, 12 & 24	---	4
	16, 19	---	3
	---	16, 17, 18, 12, 19	2
	---	10, 24	1
Total no. ratings > 50	**27**	**12**	

For PP1, the majority of these occurred in the categories of 'Mental demand' (n=7), 'Effort' (n=7), 'Physical demand' (n=6) and 'Frustration' (n=5). These results are in keeping with LSA 1's observations in their session notes, particularly where they comment on PP1 using a range of planning and problem-solving skills and becoming frustrated in some of the tasks.

For PP2 the majority occurred in 'Mental demand' (n=6) and 'Effort' (n=5). The LSAs' observations in their session notes appear to support these ratings, highlighting PP2's determination to complete tasks, level of focus and the planning and problem-solving skills demonstrated.

The number of PP2's ratings above 50 were relatively low considering the configuration errors which occurred in tasks 17, 18, 12, 19, 20 and 24. The increased difficulty involved in the tasks did not appear to affect the ratings.

There are many factors which may have influenced the workload ratings. These could be: those relating to the PPs, the setup, and the measurement process. These include:

PPs

(1) **Their level of knowledge and ability:** It is possible that the tasks revealed the limits of the participants' knowledge and abilities. The progressive increase in ratings in the NASA-TLX data suggests that the tasks may have challenged the participants' knowledge and abilities.

(2) **Sensitivity to workload:** The PP's personal nature and how they react to given stimuli. Each individual will react in different ways to a situation and variations are expected to occur.

(3) **Their condition at a particular day and time**: Given the highly complex nature of the participants' physical condition, their abilities can vary widely from day to day. This may also have affected the NASA-TLX results.

Setup and Tasks

(1) **The complexity of a particular task:** The tasks were designed to progressively increase in difficulty to explore the full range of the participant's abilities and to identify the limits of their knowledge. In doing so it was intended that the participants would be challenged and that this would be reflected in the NASA-TLX data.

(2) **The number of direction cells available at the interface**: The number of interface cells available generally increased with complexity, which may have affected the PPs' cognitive loading. More controls may have given additional freedom of movement, which could have been interpreted as reducing frustration, or as increasing complexity.

(3) **The robotics-based system design**: including whether the interface was intuitive for the PPs, whether the concept as a whole was understandable, and whether the PPs could understand how to apply the system to the task at hand.

(4) **Technical issues**: These may have contributed to frustration levels (Cook et al. 2010).

(5) **Errors in configuration**: These may have increased task complexity and frustration.

(6) **View / perspective:** As the PPs were predominantly using the onscreen view, they may have experienced difficulty perceiving depth correctly, which may have made the tasks more difficult.

(7) **Efficiency:** The number of moves it took to complete a task, the time taken and the number of errors could all add to the workload if they were high.

Measurement Process

(1) **The LSAs:** Their knowledge and understanding of a PP and also the sensitivity of their ratings i.e. some may rate higher than others.

(2) **Ratings scored 'live' or from video:** Ratings may be different between the two modes. With the 'live' mode there is an element of being 'in the moment', being more 'sensitive' to a PP's mood; immediate memories of a live session may be different to a video session where LSAs were not 'in the moment' but some time after, and were also potentially able to take more time to analyse the video.

9.4.3 Intervention: ‘Scenarios’ task group

The ‘Scenarios’ task group involved a single task: for the PPs to create a story involving a pirate ship and two characters, and then to use the robotic system to enact the story.

The ‘Directions’ stage of the intervention provided a basis for training and practice in the manipulation of the robotic arm in three dimensions. The interface design used in ‘Scenarios’ incorporated many of the features of the interface used in the final tasks of ‘Directions’, but added to these with gripping/releasing, attacking and robotic assistance. This helped the PPs to build those skills required to enact the stories involved in the ‘Scenarios’ task i.e. moving the robotic arm towards the characters and moving the characters.

This intervention stage was to evaluate the potential of robotic assisted play for the PPs. The ‘Scenarios’ interface was the most complex of all the intervention task groups.

9.4.3.1 Both PPs: Overview of ‘Scenarios’ results

As described in the Intervention Design and Administration chapter, the ‘Scenarios’ task group was designed to identify the potential of providing the TG with the ability to compose a story and enact it using the robotics-based system. This was a play activity that typically developing children engage in, but the TG may not have opportunities to do so (Musselwhite 1986).

This activity brought together the robot manoeuvring skills of the ‘Directions’ task group and the gripping (and haptic feedback) aspects of the ‘Cubes’ task stage. The task required the PPs to apply their knowledge to manoeuvre the robotic arm through a series of stages to complete their story.

‘Scenarios’ is a more difficult task stage to analyse in a quantitative manner. Since this was primarily a play task and play tasks are often unstructured, with an emphasis on fun and exploration (Besio 2008) rather than efficiency, analysis of the number of moves, or errors made is less appropriate.

Both PPs were able to design and complete their stories with little assistance required from either the researcher or the robotic helper system. PP1 created and enacted five stories over two sessions, PP2 created and enacted three stories in just one session.

Both PPs demonstrated good levels of control over the robotic arm whilst achieving the goal of story completion, using the full range of available operations i.e. left/right, up/down, forwards/backwards, gripping/releasing and so on. The NASA-TLX scores (presented later) and LSA feedback (see Appendix R - Table R.1) indicate that this task was perhaps the most difficult and challenging for the PPs, but also one of the most enjoyable.

The PPs could request assistance from the researcher or from the robotics-based system, but did not do either very frequently. Table 9.13 shows the number of requests for assistance per story.

The PPs requested help from the system more frequently than from the researcher.

Table 9.13 Number of times assistance requested by PPs – Robotics-based system and researcher

		PP1		PP2	
Session No.	**Story No.**	**Robot hint requested**	**Investigator's help requested**	**Robot hint requested**	**Investigator's help requested**
1	1	1	0	1	0
	2	2	0	1	0
	3	---	---	2	0
2	1	1	1	---	---
	2	1	0	---	---
	3	2	0	---	---

9.4.3.2 PP1: 'Scenarios'

PP1 had two sessions using the scenarios pirate ship setup. In the first session, PP1 created and then enacted two stories. In the second session he designed and then enacted three stories (see Table 9.14)

Table 9.14 PP1: Scenarios configurations

Session 1	Session 2
1. Pirate in crow's nest, crab on bow, pirate wins 2. Pirate on bow, crab in crow's nest, pirate wins	1. Pirate in crow's nest, crab on bow, pirate wins 2. Crab on bow, pirate on crow's nest, crab wins 3. Crab on crow's nest, pirate on bow, crab wins

PP1 demonstrated a good level of understanding of how to create stories and then enact them.

PP1 requested assistance seven times from the robot over the sessions and only once from the investigator (see Table 9.13). LSA 1's perception was that PP1 "gives in easily and asks for help before trying something he is unsure of".

PP1 was able to create and enact a total of five stories. These stories were successfully completed using the system. The PP demonstrated a high level of focus and engagement, with a positive emotional state.

The sessions were carried out at a warm time of year which can be uncomfortable for those who are seated in moulded seating systems. Nevertheless, he coped well – LSA 1 commented in their session notes about the impact of the heat and that PP1 appeared able to concentrate better when it was cooler.

PP1 seemed to need more reassurance with this activity than he did during 'Cubes' and 'Directions'. In their session notes, LSA 1 stated: "Seems worried about doing it wrong; likes to ask for help very quickly. Got quite frustrated when he couldn't work out what to do next. Didn't want to try something different". These were new experiences for PP1 and so he may have been apprehensive. Nevertheless, he maintained a high level of focus and engagement and was determined to complete the tasks.

9.4.3.3 PP2: 'Scenarios'

PP2 only had time for one scenarios session. He created and then enacted three stories during this session (see Table 9.15)

Table 9.15 PP2: Scenarios configurations

Session 1
1. Pirate on bow, crab in crow's nest, pirate wins
2. Pirate on stern, crab in crow's nest, pirate wins
3. Crab in crow's nest, pirate on bow, crab wins

PP2 was able to create and enact a total of three stories successfully. PP2 demonstrated a good level of understanding of how to create stories and then enact them. PP2 enjoyed the session. PP2 appeared to explore the operational limits of the robot arm.

PP1 requested assistance from the robot four times over the session but did not ask the investigator for help on any occasion (see Table 9.13).

PP2 was able to apply his knowledge to manoeuvre the robotic arm through a series of stages to complete his stories successfully. He demonstrated a high level of focus and engagement, with a positive emotional state. LSA 2 noted that he enjoyed this activity and he "chose to do the activity for a third time".

The hot weather during the sessions may have affected him, but did not appear to.

There was evidence of PP2 exerting a level of independent exploration (Cook et al. 2011) when using the arm by testing its operational limits. LSA 2 noted that PP2 "Tried pushing boundaries but the robotic arm wouldn't let PP2 do everything he wanted" and later in the session "still pushing boundaries and enjoying it".

9.4.3.4 Both PPs: NASA-TLX ratings for 'Scenarios'

Only one NASA-TLX form was completed for all 'stories' in session 1 for each PP.

The NASA-TLX scores (see Figure 9.12), show that the perception of both LSAs were that both PPs were placed under high workload in the 'Mental Demand'', and 'Effort' categories. A high rating was given for PP1 by LSA 1 for 'Physical Demand'.

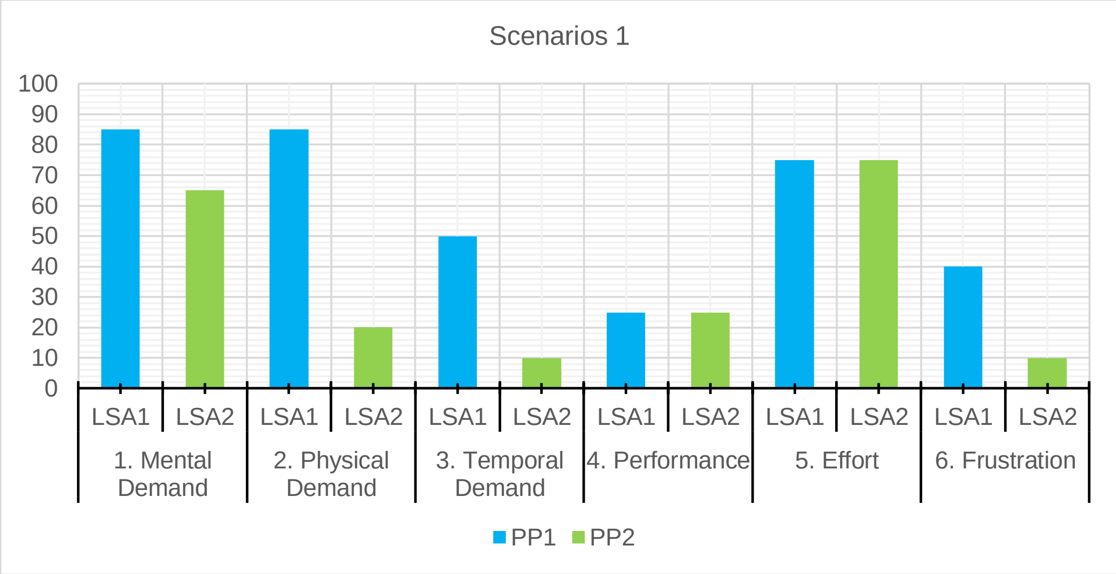


Figure 9.12 Both PPs: NASA-TLX results (Session 1 only)

9.4.3.5 PP1: NASA-TLX ratings for 'Scenarios' (session 2 only)

See Figure 9.13 for PP1's NASA-TLX scores for session 2 only. Three NASA-TLX forms were completed, one for each story, all by LSA 1:

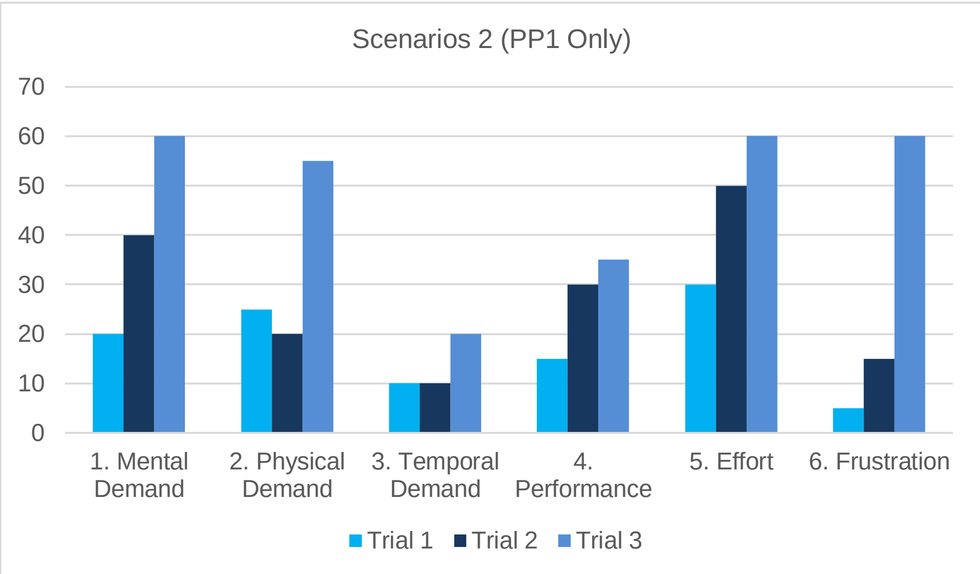


Figure 9.13 PP1: NASA-TLX results (Session 2 only)

It is unclear why the ratings increased from stories ('Trials') 1 to 3. This may have been due to a cumulative effect i.e. as the session progressed, PP1 was perceived as becoming more frustrated. LSA 1 comments upon this in their notes: "Got quite frustrated when he couldn't work out what to do next" and this may have increased the LSA's ratings for 'Mental Demand', 'Physical Demand' and 'Effort' workload.

9.4.4 *Results and Discussion of the Final LSA questionnaire (regarding all of the intervention stages)*

Once all task groups had been undertaken, the questionnaire in Appendix R was completed by the LSAs to capture some of their observations and comments about the whole intervention.

The 'Cubes' and 'Scenarios' task groups were rated as the most enjoyable for both PPs, with the 'Scenarios' task being viewed as the most difficult for both. This suggests that the intention to provide tasks of increasing complexity was achieved.

LSA 1 was surprised at how well PP1 was able to control the robotic arm, while LSA 2 indicated that she had not considered how well the PPs would be able to do this. LSA 2 also commented that both PPs performed better than expected and stated "to see both participants work out moves was amazing". This mirrors the findings of other studies (for examples see Cook et al. (2012)), regarding others' perceptions of the abilities of children with disabilities in relation to robot control.

LSA 2 was impressed by PP2's problem solving skills, determination and sustained focus and also commented on the positive effect that the intervention tasks had on PP2's mood on one occasion.

Observing the PPs using the robotic arm gave LSA 1 some ideas for work within class with PP1, particularly in relation to "positional words" such as left/right and forwards/backwards. Cook et al. (2012) also suggested that robot skills can aid the development of spatial concepts in language.

LSA 2 indicated pleasure at seeing PP2 enjoying using the system and commented on his good level of focus, or attention, to tasks. The LSAs highlighted other skills that the PPs had developed, including patience (LSA 1 said of PP1), increased awareness of left and right, "how it feels to 'hold' and move objects", and spatial awareness (LSA 2 said of PP2).

In relation to the haptic device, overall, both LSAs indicated that the device and haptic feedback were valuable, offering an experience that was 'new' and "fulfilling and interesting". LSA 1 noted that both PPs "showed signs of surprise and enjoyment".

Both LSA's indicated that they could see potential for the system to be used with the PPs with the same activities as in the intervention, or in new ones. Suggestions for other activities included: story making, sequencing, reinforcing positional words, pouring dry substances (such as rice, sand or pasta), and developing the PPs' concentration (Cook et al. 2005).

Some of the LSAs' observations and comments detailed here are similar to those of the investigator, which are described in the next section.

9.4.5 Investigator's observations and comments regarding the intervention

The PPs both appeared to enjoy using the system very much. Throughout the sessions they would frequently smile, laugh and vocalise. Both were highly motivated, focussed and determined, not wanting to give up on tasks and trying to complete them quickly. Both worked for long periods without breaks, even though they were offered.

Both PPs appeared to be surprisingly tolerant of the technical issues which occurred, with PP2 actually enjoying when things went wrong.

During 'Cubes', PP1 would sometimes begin completing a task before the investigator had finished asking the question. This may have meant that he had not fully heard the description of the task.

PP2 was sensitive to sudden noises which could cause him to startle. This could make him tense up, which could then lead to physical pain. This was the reason why the table was damped to reduce the noise of crashing blocks. PP2 was very good at anticipating when the blocks were about to crash to the table (and the noise that this would create) and would start to blink and smile but did not appear startled. Sometimes the noise of the robotic arm servos would cause him to startle if he was not expecting it.

The PPs dealt with the increasing complexity well, adapting to the interfaces and the changes in task requirements.

Both PPs seemed comfortable with the haptic device. It did not appear to distract them i.e. they did not seem to look towards their hand while the device was activating. PP2 would often smile and vocalise when the device activated.

9.5 Haptic device

It was difficult to measure the benefits and effects of using the haptic device with the PPs in this study. Reasons for this include:

Few PPs: There were insufficient participant numbers to form a separate control group. It would also have been difficult to match subjects as there is wide heterogeneity amongst disabled groups.

CCN: The TG have complex communication needs and so it would be difficult for them to provide specific feedback about the haptic device and system. Open ended questions can be difficult for them to answer and yes/no questions may be 'leading', as the investigator determines the content of the questions.

Fatigue: The PPs would often be tired at the end sessions and needed to rest, or move on to other school sessions.

Rating scales: In previous work with the TG the investigator found that they often had difficulty using rating scales.

Evaluation of the haptic device is, therefore, largely anecdotal and based upon observations during assessment and intervention sessions. Benefits included:

High haptic assessment scores: Of note is that PP2 achieved a perfect score in the haptic device outcomes assessment and PP1 answered incorrectly only once over both haptic assessments.

Responses to haptic sensations: When the haptic device triggered the PPs frequently smiled, laughed or vocalised, especially PP2. At no point did they appear to be startled by it, or complain about it. It did not appear to be distracting, or to cause any negative effects such as discomfort.

The value of the haptic device is something that could be explored further in future work. Trials could be carried out with groups similar to the TG in terms of motor ability, but with individuals who have verbal expressive communication and also typically developing CYP.

Overall, the haptic device trials carried out with SPs, use of the haptic device with PPs during the Intervention stage, and feedback from LSAs, indicated that haptic feedback provides a promising 'tool' for use with CYP who have disabilities.

9.6 Overall Analysis of results

PP1

PP1 attained very high scores in all of the assessments, both physical and cognitive. There was some evidence of confusion regarding directions throughout the cognitive assessments and during the intervention, but most tasks were completed quickly in few moves, with few errors.

PP2

PP2 frequently appeared to exhibit certain 'side-preference' behaviour patterns during the cognitive assessments but not during the intervention. It is uncertain why this was the case. There are many reasons why a person may exhibit such behaviours. A full discussion of these is beyond the scope of this study, but some possible explanations are offered here:

(1) **The Interface:** The contents of the answer cells may have been too similar. For many of the assessment questions there was a dog in all of the cells. This may have made it more difficult to differentiate between cells;
(2) **Context:** An assessment is an abstraction of ideas and concepts, when compared to carrying them out in the real world;
(3) **The differing nature of the tasks:** The cognitive assessments involved selection of an answer from a range of options, whereas the intervention tasks involved issuing commands;

(4) **Part of his condition:** Certain conditions can pre-dispose individuals to such behaviours.

Live view compared with the screen: During the sessions, the PPs were found to spend the majority of the task duration looking at the display, which was showing the live camera view during actions, but would look at the live scene more in-between tasks when the investigator was setting up the next task. The live scene was useful for interaction with the investigator and the LSA and provided real-world physical sounds and a more kinetic experience.

Side preference: PP2 rarely displayed any side-preference behaviours during the intervention. This was in contrast to the assessments.

Overall for the Intervention: The user interfaces changed throughout the tasks and the PPs adapted well to this.

Assistance: The PPs rarely asked for assistance from either the author or the robotic system. PP1 sometimes needed reassurance during the tasks, but was mostly independent

9.6.1 Evidence of PP robot-related skills

Cook et al. (2011) created a list of robot-related skills based on Forman's (1986) criteria, but tailored to children who have disabilities. Table 9.16 shows an adapted version of Cook's criteria used in the current study. It contains six main stages that can be achieved and indicative ages that these abilities develop. The table shows the Intervention task group where the skills were exhibited and the way in which the PPs demonstrated these abilities. The PPs achieved all of the stages listed thereby showing a good understanding of the skills needed to control a robot.

Table 9.16 Robot-related skills based on (Forman 1986; Cook et al. 2011)

	Skill	Definition for robot use	Age considerations* (typically developing children)	Intervention task group(s)	Evidenced by PP in the present study
0	No interaction	Child displays no interest in the robot or its actions	NA		NA
1	Causality	Understanding the relationship between an interface cell and a resulting effect	**< 3 yrs:** action is in switch, tried to use disconnected switches **> 4 yrs:** understood switch made robot move	All	Activating cells using eye gaze
2	Negation	An action can be negated by its opposite	**4 yrs:** begin to understand that switch release stops robot	NA	NA No task involved 'pressing and holding' then releasing to move and then stop the robot
3	Binary Logic	Two opposite effects such as gripping and releasing	**5–6 yrs:** understood 2 switches with opposite effects.	Cubes, Scenarios Directions and Scenarios	Gripping and releasing objects Using left/right, up/down, forwards/backwards to correct an opposite error
4	Coordination of multiple variable Spatial concepts multiple dimension	Movement in more than one dimension to meet a functional goal	**5 yrs:** Could fine tune a movement by reversing to compensate for overshoot, etc.	Directions and Scenarios	Taking food to the giraffe Moving the gripper closer towards towers or characters
5	Symbolic Play	Make believe with real, miniature or imaginary props (Musselwhite 1986)	**6 yrs:** Child ID action in robot not switch, planning of tasks is possible	Directions – Feeding the giraffe, Scenarios	Creating a story and enacting it
6	Problem solving	Problem solving with a plan – not trial and error, Generation of multiple possible solutions	**7 yrs:** Designed robot and thought about coordinated effects, planning was possible, Can understand simple programs and debug	Directions – Towers, Scenarios	Identifying the moves required to demolish a structure or move a character

9.6.2 Explanations for the PPs' knowledge and abilities

The PPs both demonstrated knowledge and abilities which they appear to have developed despite having little motor control over their own bodies. One might think that to learn about directions and physical concepts normal physical movement is required, but it appears that this may not be the case. This finding aligns with Bandura's social learning theory, i.e. that humans can learn by having others model for them (Bandura 1977) and the findings reported by Cook et al. (2012) that children who have severe motor impairments demonstrate understanding of spatial concepts through the use of assistive robots.

Human development does not happen in a vacuum. There may be many factors at work which can contribute to a person's understanding and knowledge, including prior experiences and transferable skills. In the case of the PPs this knowledge may have been gained from:

(1) **Their school education:** In class they will have been taught about concepts either explicitly or implicitly;

(2) **Being moved around by others:** The PPs are moved in a wheelchair, hoists, transport and so on. It is standard practice at VEC for staff to provide a commentary for the pupils when they transition from place to place, this may help to reinforce directions;

(3) **PP2:** At the time of the intervention, PP2 was also learning how to control powered mobility. The intervention stage may have helped him to develop skills for wheelchair control and vice-versa;

(4) **Use of technology:** The TG may have access to environmental control equipment, toys and use of eye gaze accessible software which could help them to develop their knowledge of the physical world.

9.6.3 Gaps identified in the PPs knowledge and abilities

Overall, the PPs appeared to have a good working knowledge of the concepts under investigation within this study. However, some issues were revealed:

(1) Both PPs exhibited some confusion regarding left/right, up/down and forwards/backwards but displayed good understanding of opposites which they often used to correct their mistakes.

(2) During some of the multi-part ‘Cubes’ tasks, PP1 would sometimes forget the final part of the tasks (perhaps indicative of short-term memory difficulties). Although, PP1 seemed able to hold sentences in his memory while he assembled them using his VOCA, often a lengthy process. Different memory processes may be involved in this latter ability.

9.6.4 NASA-TLX ratings

Some errors occurred during the capturing of the NASA-TLX data. This was due to the investigator trying to ensure that the forms were completed by the attending LSA whilst also setting up the next task for the PP. This placed a heavy workload upon the investigator. Ideally, the investigator would have been assisted by someone who could have ensured correct completion of the forms.

There appeared to be differences in NASA-TLX ratings between the two LSAs. Two alternative approaches to capturing ratings which may have provided more consistency are:

1) A single LSA would have attended all of the sessions for both PPs. This would have provided one set of ratings from one person.

2) Both LSAs would have attended all sessions for both PPs. This would have enabled direct comparison of ratings between LSAs and a basic measure of inter-rater reliability.

Neither option was practical in the current study.

9.7 End of Chapter Summary

Overall, both the assessments and the intervention revealed PP1's knowledge and abilities well, whereas for PP2, the intervention appeared to reveal more than the cognitive assessments.

Assessments

Both PPs were able to access the cognitive assessments directly using AT (eye tracking / gaze), with no adaptation to the assessments required, and with minimal assistance from an intermediary. This would not have been the case with most conventional assessments.

Intervention

The PPs exhibited a good understanding of many of the concepts under investigation. The PPs' abilities and knowledge revealed during the intervention tasks validated the potential of using such an approach to identify their knowledge and abilities and enabled them to have experiences that were both educational and playful.

Chapter 10 Conclusion

10.1 Introduction

This study has been concerned with those cognitively able CYP whose profound motor impairments and complex communication needs limit their ability to interact with the physical world in a ‘hands-on’ way. This deprives them of many important learning opportunities, which can be detrimental to their development and limit their prospects for participation.

The study has described difficulties in identifying the knowledge and abilities of the group of individuals described above, particularly relating to the physical world, and the lack of opportunities that they have to develop these skills.

The key objectives of this study were therefore to reveal this population’s pre-existing knowledge and abilities (in context) through assessment and the use of a suitable robotics-based physical interaction system, whilst also developing this knowledge and ability through the use of such a system.

This chapter includes a summary of the work, examines how the original research questions were addressed, highlights the original contributions, and reflects on the findings and implications, before finally considering future directions that may be pursued.

10.2 Summary

A review of the literature revealed a number of gaps, including a lack of assessments which were suitable for the TG, and appropriate physical interaction experiences for them. These gaps formed the research motivations and direction of this work. Key gaps that were revealed include: existing assessment approaches are unsuitable for the TG; no existing studies could be found concerning the use of haptic feedback technology with those who have the characteristics of the TG; there were few suitable ways for the TG to have independent physical interaction experiences, due to a shortage of suitable robotic systems to provide these experiences for them; there is currently a lack of English language AT accessible spoken language comprehension assessments suited to individuals who have profound motor impairments - the majority of assessments are designed for use with typically developing children, or those who are able to provide answers verbally or through physically pointing, and are thus unsuitable for the TG; no assessments suitable for use with the TG were identified which could be used to assess their ability to accurately identify physical touch and haptic sensations in the palms of their hands.

Given these apparent gaps in the current state-of-the-art, a set of assessments were designed, a robotics system with eye gaze control and haptic feedback was constructed, and an experiment was conducted.

Assessment can enable individuals to demonstrate what they know and are able to do. It also enables therapists and education staff to measure progression and identify strengths and gaps, and to then target these gaps. New cognitive assessments were designed using both static image and video based approaches which could be accessed by the TG. These were then deployed to assess the participants' knowledge and understanding of primarily spatial concepts.

Using robotics-based systems to provide stimulating experiences can also contribute to the TG's development in terms of knowledge and understanding. Such systems could enable them to demonstrate their knowledge and abilities and could provide them with a means of participating in activities. Having more control and greater involvement in activities may also help to limit or reduce passivity. To address these points, a robotic arm system with haptic feedback was combined with eye gaze control to enable the participants to manipulate a test environment.

The TG have limited opportunities for self-directed tactile experiences and a review of the literature identified a lack of 3D physical interaction systems incorporating haptic feedback which were suitable for use by the TG. Such haptic feedback devices could provide a useful substitute for actual physical touch. A custom palm-based haptic device was designed and constructed for this research and combined with the robotics-based system to provide haptic feedback when the robot arm grips an object.

An experiment was designed which brings all of the above aspects together. This consisted of a baseline assessment followed by an intervention and concluded with an outcome measures assessment. The intervention stage consisted of using the robotics-based system to complete a set of progressively more complex tasks. Similar to the assessments, the tasks were designed to reveal the TG's knowledge and abilities relating to the concepts under investigation, but this time through 'doing' rather than a more 'formal' assessment approach.

The experiment was carried out with two pupil participants (PPs). The results show that the PPs appeared to have a good working knowledge of many of the concepts under investigation within this study. They both demonstrated knowledge and abilities relating to spatial concepts which they appear to have developed despite having little motor control over their own bodies. The experiment also revealed some limitations of this knowledge, where both PPs exhibited some confusion regarding left/right, up/down and forwards/backwards but displayed good understanding of opposites, which they often used to correct their mistakes.

Both the assessments and the intervention revealed PP1's knowledge and abilities well, whereas for PP2, the intervention revealed more compared to the cognitive assessments. The PPs' abilities and knowledge revealed during the intervention tasks validated the potential of using such an approach to identify such skills and enabled them to have experiences that were both educational and playful.

In conclusion, the experiment showed that the test setup was appropriate for revealing knowledge about the participants that had not previously been known.

10.3 The RQs and how they were addressed

In the Introduction chapter the following research questions (RQs) were posed. How these were addressed by this study is now considered:

Overarching Research Question (RQ): *How can the TG's knowledge and abilities relating to the physical world be revealed and developed using technology?*

Overarching Research Aim (RA): *To use suitable assessment techniques to reveal the TG's knowledge and abilities relating to the physical world and to develop these using a robotics-based system.*

A range of assessments and an eye gaze controlled robotics-based system with haptic feedback were created. These were used with members of the TG to reveal their knowledge and abilities relating to the physical world. Both PPs quickly mastered using the robotics-based system and revealed a good understanding of the concepts under investigation. The assessments were particularly effective for revealing PP1's knowledge and abilities, with scores near or at ceiling. The assessments were less effective when used with PP2 with particularly low scores during the cognitive assessments.

This demonstrates that making assessments accessible may make them suitable for assessing some individuals, but not others.

RQ1*: Can the TG accurately identify physical touch and haptic sensations in the palms of their hands and how can this be measured?*

RO1: *To develop and evaluate physical touch and haptic feedback assessments, and suitable haptic feedback devices.*

How RQ1 and RO1 were addressed:

Two physical touch assessments were developed. The results of these assessments indicated that the PPs could identify physical touch and haptic feedback sensations in the palms of their hands. PP1 achieved ceiling or near ceiling scores in all physical assessments. For PP2 the haptic feedback method yielded higher scores than the physical touch especially during the outcomes assessment, where he achieved a score at ceiling.

RQ2: *How can the TG's knowledge of physical world concepts be revealed using technology?*

RO2: *To reveal the TG's knowledge of physical world concepts.*

How RQ2 and RO2 were addressed: Two English language AT accessible spoken language comprehension assessments were created to assess the concepts under investigation in this study. The results indicate that they were suitable for PP1 but less so for PP2. The intervention was also designed to reveal this information, which it appeared to do well for both PPs.

RQ3: *How could a robotics-based system be used to provide the TG with independent simulated physical interaction experiences?*

RO3: *The creation of a robotics-based system which provides the TG with independent simulated physical interaction experiences.*

How RQ3 and RO3 were addressed: A robotics-based system was created with an eye gaze controlled user interface. Both PPs were able to control the robotic system well and demonstrated a good understanding of how to control it.

RQ4: *Does the intervention reveal and develop the TG's knowledge and abilities relating to the physical world?*

RO4: *Use of the physical and cognitive assessments and intervention tasks to identify the TG's knowledge and abilities relating to the physical world.*

How RQ4 and RO4 were addressed: This was unclear from the results obtained during the assessments and intervention. PP1 revealed good to high levels of knowledge and ability throughout all assessments and the intervention, indicating that the assessments worked well for this PP. PP2 did not demonstrate consistent results, especially regarding the cognitive assessments. The intervention tasks appeared to be a more appropriate method for revealing PP2's knowledge and abilities in the context of this study.

10.4 Contributions

This study makes contributions to knowledge in the field of disability and Assistive Technology.

Key Contributions

1. *The development of a robotic augmentative manipulation assistive technology, accessible through eye gaze and providing haptic feedback, that can support participation in academic and play activities, and also reveal the cognitive skills of young people (and children) who have severe motor impairments. This included:*
    - A new means of enabling the TG to have simulated physical experiences, through the combination of a robotics-based system and a haptic device which triggers when the robot arm grips an object;
    - 'Live' and alternating 'camera' / control views of the scene, advancing knowledge of how the TG can interact with such a setup;
    - Robot assisted play, with the TG using a robot arm, in a narrative format with multiple narrative paths;
    - Insights into the understanding of the TG: they appear to have a greater understanding of temporal, spatial and movement concepts than anticipated; and they are able to control a proxy robotic arm in 3D space, despite having very limited control of their own limbs.

2. *Two approaches to English language AT accessible spoken language comprehension assessment using video and static images:*
    - Specifically relating to the design of assessments which are suited to complex individuals – in particular those who use eye gaze as their primary access method;
    - Employing video clips, rather than static images, may be a more appropriate way of depicting and assessing concepts which involve movement.
3. *A prototype haptic device suitable for the TG (and prototypes which may be suitable for other individuals who have disabilities) used to assess the ability to detect sensations:*
    - Use of the device revealed a better than expected ability of the TG to detect haptic sensations in the palm areas of their hands.

Supplementary Contribution

4. *Contributions 1-3 have developed insights into designing for, and working with, the TG:*
    - An advancement in the consideration of the requirements and needs of the TG and how to supply them with AT equipment, in terms of robotics, haptics, and interfaces;
    - A proxy user centred design was used and evaluated successfully, indicating that this is a viable design methodology for the TG.

10.5 Reflections on the study

This work comprised a great many sub-components, which were all brought together into the core experiment. In this section, the larger sub-components are evaluated for their effectiveness of design and implementation.

10.5.1 Evaluation of the system design approach

The design approach that was used for this study involved eliciting requirements by analysing the characteristics of the TG and comparing them with those of existing approaches to identify gaps and perceived requirements; and the 'proxy UCD' approach to developing the haptic prototypes and the robotics-based system appeared to work successfully.

Referring back to desirable design characteristics for assistive robots Cook et al. (2010), the robotics-based system design matched many of Cook's criteria. The system was **safe**, relatively **low-cost**, catered for a wide range of alternative **access** methods. The PPs were able to quickly and **easily learn** how to use the system and **comfortably**, demonstrating that the user interface was **intuitive** and **accessible** and provided good control over the robot. The **autonomy** of the system decreased over time, gradually handing the autonomy to the PPs. The system provided **feedback** in the form of sound, speech and haptic sensations. The activities were designed to be visually engaging (**aesthetically pleasing**), motivating and fun. The reactions of the PPs and the comments from the LSAs indicate that this was achieved. Where the system was not so successful was in terms of **reliability**, encountering a number of malfunctions, especially relating to failure of the eye gaze unit to track the PP's eyes. Encarnação (2016) also noted problems with using eye gaze technology for the purposes of controlling robots. Portability was also an issue, but a collapsible mounting system was later created which improved this aspect considerably.

The PPs were able to use the system effectively. They did not seem to have any difficulties understanding the HRI. They seemed to understand the various layouts of the different user interfaces with little instruction. Switching between a command interface and the live view ('command then view') appeared to work well. In fact the PPs spent most of their time viewing the screen. This may have caused perspective errors, seeing the scene from only one view point, but may have been more comfortable for them.

The 'command then view' approach used in this study had the benefits of maximising the size of the interface cells, making them easier to target for eye gaze users. The approach also helped to avoid the switching back and forth between a screen and the live scene noted by Encarnação et al. (2016), and also reduced the 'doing something over here causes something over there' confusion that might occur (Forman 1986).

Before selecting a command cell the PPs needed to activate/'un-rest' eye gaze operation each time by dwelling on the  cell. This was designed to avoid the 'Midas' effect (Jacob 1990) and to ensure that each command was intentional. This worked well for the most part, helping to pace input and reduce unintentional selections, but sometimes caused misunderstandings when a PP had not realised that they still needed to activate eye gaze.

There were a number of system reliability issues. As noted by Encarnação et al. (2012a), physical robot systems are prone to technical issues and so need to be supported well. A virtual approach, whilst lacking in certain areas, may be more reliable and require less physical space.

In terms of the **design** of the haptic device, there were many positives: it worked very **reliably** with no apparent issues throughout the assessments and the intervention; it was easy and quick to don/doff; it was robust, coping well with PP1's involuntary movement with no signs of wear or damage; the device remained attached at all times; it did not get in the PPs' way; it did not seem to distract the PPs.

10.5.2 Evaluation of the assessments

The assessments created for this study achieved varying levels of success. The physical assessments appeared to realise the intended aims of the study for both PPs, whereas the cognitive assessments appeared effective for one but not both participants. The intervention stage revealed a high level of proficiency and understanding for both participants, showing them to be more knowledgeable and able than might be expected for individuals with such profound physical limitations.

The two approaches used to assess the TG, i.e. through the more 'formal' assessments approach and through 'doing' during the intervention, suggest the importance of different forms of assessment for different individuals. Both or either method ('formal' assessment and 'doing' assessment) may be suitable for some, whereas for others, only one may reveal their knowledge and understanding effectively. Both the assessments and the intervention revealed PP1's knowledge and abilities well, whereas for PP2, the intervention revealed more than the cognitive assessments.

It is the author's opinion that, where possible, a combination of the two approaches could help provide a clearer, more rounded understanding of such individuals.

10.5.3 Evaluation of the haptic device

The measurable benefits of the haptic device use during the intervention are less clear. The staff participants felt it was an important component of the robotics-based system and the PPs appeared to enjoy the experience that it contributed, often smiling, laughing or vocalising when the device activated. The haptic feedback assessment results for PP2 showed a marked improvement between the baseline and outcome stages. Some of this improvement in PP2's haptic feedback assessment results may be attributable to the use of the haptic feedback device during the intervention.

Haptic feedback adds another component to the 'hands-on' aspect of object manipulation (Jafari et al. 2016). This work has covered the creation and viability of a haptic device which is suitable for the TG, which can now enable further work in this direction.

10.5.4 Virtual versus physical robotic systems

In the current study it was found that the PPs spent the majority of the intervention sessions attending to the onscreen view of the scene which adds credence to virtual approaches.

However, during the set up period between tasks the PPs often looked at the live scene watching the investigator set up the next task. This perhaps provides a 'learning by observation' opportunity (Bandura 1977) for the TG which may be missing from virtual approaches whereby the pre-built activities are loaded with no indication to the participant of how they were set up.

This perhaps illustrates the validity of both approaches rather than either having superiority. This is supported by Encarnação et al. (2014) who observed that participants' performance was similar between the physical and virtual versions of their robotic system designed for children who have motor impairments. They stated that the virtual version overcame some of the limitations of physical robots 'such as cost, reliability and the need for on-site technical support'.

10.5.5 NASA-TLX

NASA-TLX was useful for estimating the workload being placed upon the PPs whilst using the system. It is important to avoid overloading this vulnerable group of individuals. The ratings were therefore given by a proxy, which gave some indication of workload levels. However, the 'proxy' nature of this approach meant that the ratings were subjective. There also appeared to have been inconsistencies in the raters' scoring.

10.6 Implications of the study

There are theoretical and practice-based implications for the findings and outputs of this study.

It appears that the TG are able to develop knowledge and abilities relating to the physical world despite not being able to interact with it under their own volition.

One possible explanation for this relates to Bandura's social learning theory i.e. that learning can take place by watching others or by having others model behaviours for them (Bandura 1977). For example: carers providing verbal commentary when carrying out tasks or moving the person's wheelchair such as 'I'm going to move you backwards'. The TG may compensate for their physical restrictions by becoming skilled observers.

The TG also have a variety of other learning opportunities. For example, Physiotherapy treatment in the form of active and passive exercises may help the TG to develop an understanding of joint movement and manipulation and help with their proprioception.

However, it is not clear how the PPs were able to take control of the robotic arm and understand how to use it to complete the tasks. This required them to understand that they were in control of the position of the gripper in 3D space. Having little or no control over their own limbs means that they have limited experience of positioning themselves or objects within 3D space. This could be an area of further investigation.

This work has implications for professional practice by providing ways to develop a deeper understanding of the TG, through the assessment, intervention and technology sections of this study.

Until suitably accessible standardised assessments arrive, the two digital AT assessments that were developed could be used by practitioners to assess those for whom existing methods are inadequate. The assessments natively provide a means for the TG to use their preferred access method rather than practitioners having to modify the assessments to suit the access method. The 'wrapper' method used in the static image-based assessment provides a resource that could be adapted to create suitable informal accessible assessments, and could inform the direction of future AT accessible assessments. Furthermore, the use of video clips in assessments may be a less abstract means of representing certain concepts compared to their static equivalents.

There are numerous possible applications for the robotics-based system for achieving therapy and educational goals, including such activities as toy-based play, and weighing and measuring. The robotics-based system could be used by practitioners with their profoundly physically impaired clients to achieve some of these goals.

The haptic device created during this study could be used by practitioners for assessment purposes, for manipulation experiences as was the case in the current study, or for sensory feedback purposes to improve body awareness.

10.7 Limitations of this study

This work was subject to a number of limitations, solutions to which may form future work.

Number of Participants: As this was a pilot study, only two participants belonging to the TG took part. It is recommended that the outputs of this research are trialled with a larger number of participants. This may increase the significance and generalisability of the data gathered.

Comparison with TD CYP, or similar groups: The outputs were not trialled with a typically developing group. Such trials could be used as a benchmark against which the TG's performance levels could be compared, although care needs to be taken when making comparisons between these two groups, as their life experiences will have been different and thus their relative strengths and weaknesses will differ.

Length of study: The intervention period was short and so the PPs had relatively few sessions. Greater exposure to the intervention over a longer period may be required to develop a clearer picture. The range of concepts examined could also be expanded.

Design approach: The design stage did not involve UCD, which would have been the ideal approach. Nevertheless, the use of 'proxy' UCD worked well and produced assessments and a robotic system which the PPs were able to access.

Assessments: This study required that a relatively small number of concepts be assessed. To establish the efficacy of the design and suitability of the cognitive assessments, a wider range of concepts should be tested.

The video-based assessment did not allow the PPs to select answers using the direct 'dwell-select' method. Instead, the PP's fixation was interpreted by the administering therapist. Direct dwell-select should be added to future versions of the assessment.

Robotics-based system: The robotics-based system did not fulfil the requirement of being reliable. This is a recognised problem of using low-cost adapted robots (Cook et al. 2010), but as there is currently a lack of suitable commercially available robots, researchers and Assistive Technologists are left to adapt mainstream technologies.

Haptic feedback device: There were limited measures in place to identify what value was added by the use of the haptic feedback device. However, the haptic sensations assessment results did show a significant increase for PP2's scores between the baseline and outcomes stages. This could be attributed to the use of the haptic device both during the baseline assessments and the intervention, directing PP2's awareness to his hands.

In addition, the VEC staff who were involved considered the haptic device to be an important component of the system. The PPs seemed to enjoy wearing the device and the experience that it provided.

The haptic device created and used within this study provides a rudimentary sense of touch. More advanced approaches exist which use pressure to deliver a more realistic sense of touch. However the cost of such devices is high and their designs more invasive. The device used in this study has the benefits of low cost and is simple to fit.

10.8 Future work and recommendations

Digital assessments are needed which are both AT accessible and contain content which is appropriate for the groups being assessed. There is a need for low cost, reliable systems which can provide physical interaction experiences and access to activities, toys and play for groups such as the TG. Robotics and haptic feedback could form an important part of such systems.

10.8.1 Assessments

a) **Accessibility of assessments**: Without adaptation most current assessments are not accessible for the TG. It is recommended that assessment providers offer digital versions of their assessments which also incorporate accessibility features, or which can run within accessibility software such as Grid 3 (as was done in the current study), making them appropriate for a broader range of individuals, including users of AT.

b) **Standardisation of assessments:** Most existing assessments are standardised using TD groups. There can be significant differences between the life experiences of the TD and differently able groups which can lead to unfair comparisons being made. Additional standardisation using populations who have similar impairments to the TG is recommended.

c) **Assessment content**: As a result of differing life experiences and vocabulary development, content may need to be adapted to suit groups who have disabilities.

d) **Mode of presentation**: Video clips may be more appropriate for assessing certain concepts, such as those involving movement. It is recommended that this approach is used more within digital assessments.

e) **Perseveration**: One of the participants of this study exhibited behaviour that could be regarded as perseveration. Further work is required to understand this phenomenon and how assessments could be designed to avoid triggering this behaviour.

10.8.2 Robotics-based systems

To achieve widespread adoption within special education environments, solutions need to be affordable, reliable and easy to use, and well supported. The system described within this study, whilst relatively affordable, is still complex and currently requires a high level of technical support. It also had intermittent technical issues which made it unreliable at times. With these factors in mind future directions for this area of work could include:

a) **Addressing the lack of suitable robots:** In line with Cook et al. (2010) and Miguel Cruz et al. (2017) it is recommended that low-cost purpose built robots are created for CYP who have profound motor impairments. End-users, researchers and industry should work together to address this situation.
b) **Addressing the lack of accessible HRIs:** Cook et al. (2010) also highlighted the lack of accessible HRIs. This is especially true for many modern computer or tablet-based 'app' controlled technologies which often use Bluetooth technology. Such apps are not accessible to many who have disabilities as fine motor control is required. Furthermore, unlike infrared signals, the radio frequency signals emitted cannot easily be captured and so AT IR learning devices cannot be used. AAC software such as Grid 3 can be used to provide an accessible interface, but often requires 'middleware' software to be created to provide a bridge between the toy or robot and the interface, as was done in the present study. There is also the additional cost of this software. Companies could open up their robot communication protocols and work with stakeholders, researchers, Assistive Technologists and the open source community to develop alternative access software which provides both the accessibility features and the connectivity to mainstream robots required.
c) **The 'Maker' movement**: There are an increasing number of mass-market and hobbyist robotic devices entering the market, some of which could be adapted, or interfaced with, via AT. For those who are technically minded, Arduino-based robotics are particularly flexible in terms of interfacing and are low-cost.
d) **Communication pages:** These could be combined with robot control pages to allow the PPs to communicate whilst using the robot, as typically developing children do (Adams 2011). This might also enable the participants to provide an indication of the workload demands they are experiencing.
e) **Use with other groups:** Such systems could also be used with other groups such as those who have spinal injuries.
f) **Scale up**: Experiences could be made to be more immersive and realistic, involving more precise robotics and more realistic feeling haptic devices, however, this would raise the cost and complexity of such systems.

10.8.3 The Intervention

a) **Other tasks:** During this study, the LSAs who were involved suggested other ideas for using the system, for example creating other stories using different resources.

b) **Examine a wider range of concepts using tasks:** Such as in front of, behind, above, below.

10.8.4 Haptics

Overall, the haptic device trials carried out with SPs, use of the haptic device with PPs during the assessment and intervention stages, and feedback from LSAs, indicated that haptic feedback provides a promising 'tool' for use with CYP who have disabilities. Haptic feedback may be useful where physical contact is not possible due to motor impairment. It is recommended that haptic devices are used to reinforce contact experiences during assisted manipulation experiences.

The haptic prototypes developed during this study have a number of further future possible applications:

a) **Virtual Environments:** Haptic devices could be used with virtual environments, combining the benefits of affordable, easy to support virtual systems with a simulated physical component.
b) **Boundaries, collisions and guidance:** When using robots, haptic feedback could be used to alert the TG of scene boundaries or to help them to 'feel' collisions, or even to help guide them towards objects of interest.
c) **Further trials:** Trials could be carried out with groups similar to the TG in terms of motor ability, but who also have verbal expressive communication, and/or typically developing CYP to gather feedback and establish the value of the haptic devices.

10.9 Conclusion

The TG face even greater restrictions on their life experiences than most who have disabilities. This can impact upon their development and ability to experience and participate. This need not be the case. Research and technological advances can provide new mechanisms which help to provide this group with experiences that are available to their typically developing peers.

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Appendices

Appendix A TG comparison with ICF-CY

Description of the target group (TG)

The group of individuals or target group ('TG') who are the focus of this research, consists of cognitively able young people who have profound motor impairments. To provide a deeper understanding of the TG's disabilities, they are compared here against the International Classification of Functioning, disability and health: Children and Youth version (ICF-CY) (World Health Organization 2007).

Disability and the ICF-CY

Disability is a complex topic and a full discussion is beyond the scope of this study. The ICF-CY (World Health Organization 2007) is very detailed but sections pertinent to this research will be used here to illustrate the functional levels of the TG, together with examples of how these levels may impact upon their development. This will help to build a profile of the TG and also demonstrate some of the barriers that they face.

A.1 ICF-CY Section: BODY FUNCTIONS

Mental Functions

Although members of the TG have 'good' cognition (see Inclusion criteria in the Methodology chapter), some may have cognitive impairments:

- The difficulties involved in assessing this group using standardised testing methods may mean that some cognitive disabilities (and abilities) may go unnoticed.
- Developmental delay may occur as a secondary effect resulting from restricted life experiences.

Example Impacts

- They could have undiagnosed cognitive disabilities relating to e.g. memory, intellect, thinking.
- It is likely that they will have gaps in their knowledge due to a lack of experience.
- Executive functions (see Glossary) may be affected by a lack of experience.
- They may have difficulties with perception through a lack of exposure to situations.
- They may have underdeveloped receptive and expressive language.

Sensory functions (and pain)

The TG may experience sensory stimuli differently. They may have:

- Limited knowledge of the properties of objects through a lack of 'hands-on' experience.
- Altered sensation e.g. hypersensitivity / hyposensitivity.

Example Impacts

- They may be unaware of differences in size, shape or colour.
- They may not be able to process sensory input effectively.

Neuromusculoskeletal and movement-related functions

Those in the TG have severe physical limitations, comprising:

- Severe motor control impairments involving all limbs. Any intentional movement may be variable, slow and require huge effort.
- Involuntary movement may be present.

Example Impacts

- They are likely to be completely unable to manipulate objects without AT.
- They will be unable to receive tactile feedback through intentional touch.
- They may lack almost all physical control of their body.

A.2 ICF-CY Section: ACTIVITIES AND PARTICIPATION

Learning and applying knowledge

The TG individuals may have difficulties "learning, applying the knowledge that is learned, thinking, solving problems, and making decisions":

- Conventional approaches to learning and applying knowledge may not be possible e.g. expression using speech and language and physical activities such as writing.
- A person's disabilities and a non-supporting environment may cause interruptions to their education.

Example Impacts

- They may have developmental delay.
- There will be many interruptions to their education, including the need to attend therapeutic sessions, hospital appointments etc.

Communication

Those in the TG have communication impairments:

- The TG may have difficulties with communication in all modalities, i.e. non-verbal communication, verbal and written expression, auditory and written comprehension. They may have some ability to vocalise. Communication impairments may result from damage to the oromotor apparatus, cognition or both. They will be heavily reliant upon communication partners or a Voice Output Communication Aid (VOCA). Their usual form of communication involves eye-pointing using symbol-based systems, both low-tech (Communication Book – see Glossary) and high tech (eye gaze systems), but they may also have some literacy. Although they are unable to use sign language to express themselves, it may be used by others to aid their understanding.

Example Impacts

- The TG may rarely have the opportunity to ask questions such as 'what is that?'
- Conversation may be slow and involve the use of simple sentences often consisting only of verbs and nouns.

Mobility

Members of the TG have mobility limitations:

- They are wheelchair users, but are unable to propel themselves manually. Additionally, they are unlikely to successfully access assistive technology alternatives such as powered wheelchairs.
- They are often unable to maintain a body position without proper support.
- They may have little or no reliable intentional control over limbs, hands and digits.

Example Impacts

- They are unable to crawl, walk or stand unaided.
- They will have no means to explore or move closer to something in order to examine it without AT.
- With limited ability to support their trunk, limbs and head, they often need support harnesses to keep them safe and in a good posture.
- They are unable to manipulate objects without AT.
- They cannot use touchscreen devices, a computer keyboard or mouse and are unlikely to be able to use alternative conventional assistive technologies such as 'switches'.
- Without physical interaction, the TG will observe others doing an activity, but this may not be the same as experiencing it first-hand.

A.3 ICF-CY Section: ENVIRONMENTAL FACTORS

Products and Technology

The TG may face barriers resulting from the design of their environment:

- They may be unable to interact physically with conventional environmental features such as doors, electrical light switches, remote controls etc.

Example Impacts

- Without adaptions, such as environmental control equipment, the individual will have little or no control over, or interaction with, their environment. This will make them heavily reliant upon care-givers, which may lead to 'learned helplessness' or passivity.

A.4 Additional background information about the TG

Medical and therapeutic needs

- The TG require ongoing therapeutic treatment from a large team of health care professionals including doctors, nurses, physiotherapists, occupational therapists and speech and language therapists.

Care needs

- The TG are heavily reliant upon caregivers for all aspects of personal care (e.g. toileting, washing, and dressing) as well as the provision of nutrition and hydration.

Eating and drinking

- The TG may receive nutrition and hydration by alternative means i.e. via a feeding tube (non-orally).

Appendix B Concepts under investigation

The concepts under investigation during this study are shown in Table B.1. These span a range of temporal, spatial and movement concepts and were focussed on within various stages of the intervention.

Table B.1 Concepts under investigation

Concept	Assessments: Physical – Touch and haptic	Assessments: Cognitive – Static image-based	Assessments: Cognitive – Video-based	Intervention: Cubes	Intervention: Directions	Intervention: Scenarios	Concept type	Task group	Example language used in sessions (by investigator or system)
Red		●		●			Adjective	Cubes	Put the **red** cube in the box
Green		●					Adjective	Cubes	No green cube was used
Blue		●		●			Adjective	Cubes	Put the **blue** cube in the box
Yellow		●		●			Adjective	Cubes	Put the **yellow** cube in the box
Left	○	●	♦	●	●	●	Preposition	Cubes, Directions & Scenarios	The tower is on the **left**
Moving left			●		●	●	Verb + Preposition	Cubes & Scenarios	Moving left
Right	○	●	♦	●	●	●	Preposition	Cubes, Directions & Scenarios	The tower is on the **right**
Moving right			●		●	●	Verb + Preposition	Cubes & Scenarios	Moving right
Middle		●	●	●	●		Preposition	Cubes & Directions	Put the **middle** cube in the box
Up			♦		●	●	Preposition	Directions & Scenarios	Move up
Moving up			●		●	●	Verb + Preposition	Cubes & Scenarios	Moving up
Higher		●			●	●	Preposition	Directions & Scenarios	You will need to move the gripper **higher**/up
Above		●			●	●	Preposition	Directions & Scenarios	The gripper is **above** the tower
Down			♦		●	●	Preposition	Directions & Scenarios	Move down
Moving down			●		●	●	Verb + Preposition	Cubes & Scenarios	Moving down
Lower		●			●	●	Preposition	Directions & Scenarios	You will need to move the gripper **lower**/down
Under		●			●	●	Preposition	Directions & Scenarios	The tower is **under** the gripper
Forwards			♦		●	●	Adverb	Directions & Scenarios	Move forwards
Moving forwards			●		●	●	Verb + adverb	Directions & Scenarios	Moving forwards
Backwards			♦		●	●	Adverb	Directions & Scenarios	Move backwards
Moving backwards			●		●	●	Verb + adverb	Directions & Scenarios	Moving backwards
In front		●			●	●	Preposition	Directions & Scenarios	The … is **in front** of the gripper
Behind		●			●	●	Preposition	Directions	The tower is **behind** the gripper
On		●		●			Preposition	Scenarios	The <winning character> **on** the <location>
In		●		●			Preposition	Cubes	Put the 'x' cube **in** the box
Far apart		●			●	●	Preposition	Directions & Scenarios	Too **far apart**/too far away
Near		●			●	●	Preposition	Directions & Scenarios	The gripper is **near** the tower
Gripping			●		●	●	Verb	Cubes & Scenarios	Gripping
Releasing			●		●	●	Verb	Cubes & Scenarios	Releasing

Key

● indicates the sections in which the concept occurs

○ indicates that left and right were involved, but not verbally

♦ movement was involved

Appendix C SP Trials: Round 1 - Physical Assessment

Practice Answers

Participant's Name: ____________________________ Date: ___________ Time: __________

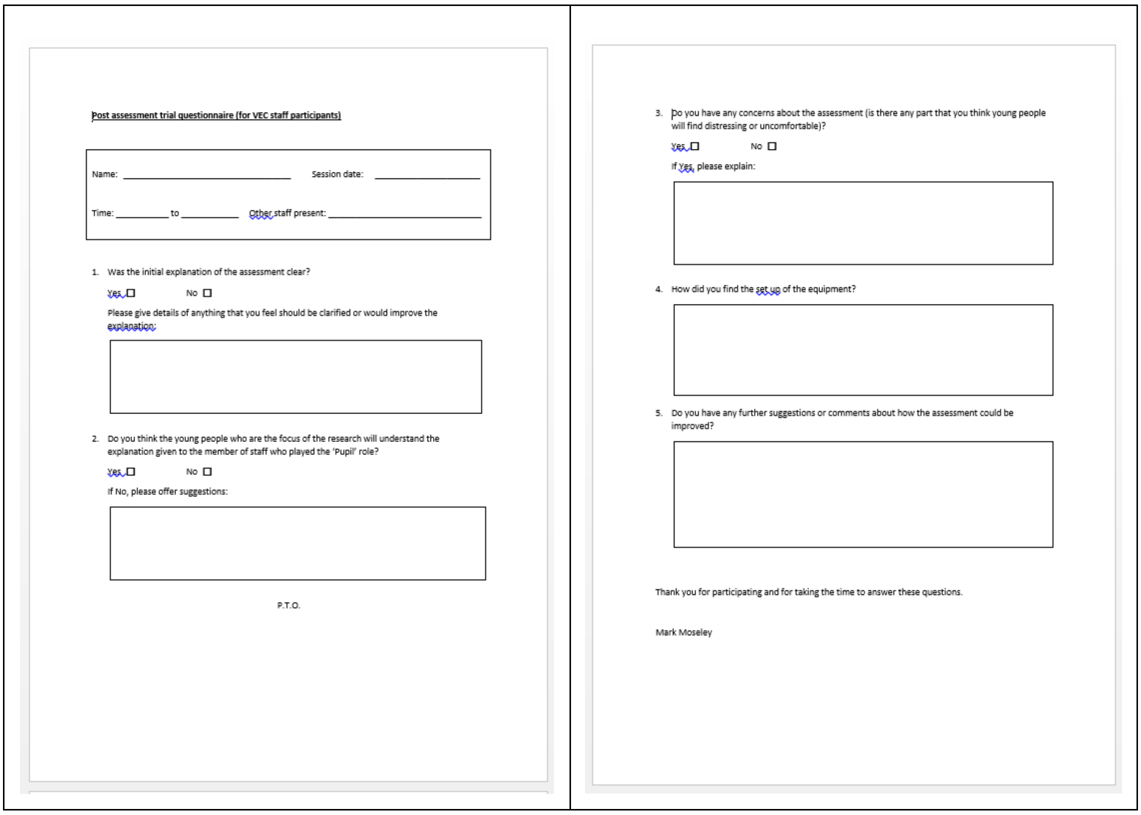
With hands visible

Trial Number	Hand stimulated	Participant's response	Correctly identified		
1	Left		Yes		No
2	Right		Yes		No
3	None		Yes		No
4	Both		Yes		No

With hands hidden

Trial Number	Hand stimulated	Participant's response	Correctly identified		
1	Left		Yes		No
2	Right		Yes		No
3	None		Yes		No
4	Both		Yes		No

Figure C.1 SP Trials: Physical assessment form (Hands)



Post assessment trial questionnaire (for VEC staff participants)

Name: ______________________ Session date: ______________

Time: ________ to ________ Other staff present: ____________________

1. Was the initial explanation of the assessment clear?

   Yes ☐ No ☐

   Please give details of anything that you feel should be clarified or would improve the explanation:

2. Do you think the young people who are the focus of the research will understand the explanation given to the member of staff who played the 'Pupil' role?

   Yes ☐ No ☐

   If No, please offer suggestions:

P.T.O.

3. Do you have any concerns about the assessment (is there any part that you think young people will find distressing or uncomfortable)?

   Yes ☐ No ☐

   If Yes, please explain:

4. How did you find the set up of the equipment?

5. Do you have any further suggestions or comments about how the assessment could be improved?

Thank you for participating and for taking the time to answer these questions.

Mark Moseley

Figure C.2 SP Trials: Physical Assessment - questionnaire (Form)

Table C.1 SP Trials: Physical Assessment – questionnaire (Answers)

Question 1				
Group No.	**SP No.**	**Occupation**	Q1. Was the initial explanation of the assessment clear?	Please give details of anything that you feel should be clarified or would improve the explanation:
1	14	SaLT	Yes ☒ No ☐	< No answer given >
	19	OT	Yes ☒ No ☐	It just looked like there was quite a lot of paperwork that researcher was trying to negotiate
2	8	LSA	Yes ☒ No ☐	The instructions were very clear and the brief informative.
	12	OT	< Form not returned >	
3	15	Teacher	< Form not returned >	
	1	LSA	Yes ☒ No ☐	Nothing. I thought the explanation was quite clear.
Summary				
			Y: 4 N: 0	• Too much paperwork. • Clear explanation.

Question 2				
Group No.	**SP No.**	**Occupation**	Q2. Do you think the young people who are the focus of the research will understand the explanation given to the member of staff who played the 'Pupil' role?	If No, please offer suggestions:
1	14	SaLT	Yes ☒ No ☐	Well explained, especially with updated symbols, and use of Makaton to support the symbols during their explanation
	19	OT	Yes ☒ No ☐	< No answer given >
2	8	LSA	Yes ☒ No ☐	As mentioned after the assessment, visual clues may also help when explaining the 'activity'. For example, picture of both hands, left hand etc. so the pupil will already have an understanding of what they are to look out for on the E-tran.
	12	OT	< Form not returned >	
3	15	Teacher	< Form not returned >	
	1	LSA	Yes ☒ No ☐	< No answer given >
Summary				
			Y: 4 N: 0	• Good explanation. • Use symbol cards and Makaton sign language

Question 3				
Group No.	**SP No.**	**Occupation**	Q3. Do you have any concerns about the assessment (is there any part that you think young people will find distressing or uncomfortable)?	If Yes, please explain:
1	14	SaLT	Yes ☒ No ☐	I think some students may find something happening which is hidden from them a little strange or worrying initially, but every effort is being made to reassure them and explain, with the trials first being done in their sight. Staff also are being asked to monitor for any signs of distress or anxiety. I don't have concerns that would make me feel it is not appropriate, but need to be responsive to the students' reactions if needed.
	19	OT	Yes ☐ No ☒	< No answer given >
2	8	LSA	Yes ☐ No ☒	< No answer given >
	12	OT	< Form not returned >	
3	15	Teacher	< Form not returned >	
	1	LSA	Yes ☐ No ☒	Although. Shorter groups of questions with students who need assistance keeping hands still would be good.
Summary				
			Y: 1 N: 3	• Be aware of needs of PPs. • Help with keeping hands still. • Shorter groups of questions

Question 4			
Group No.	**SP No.**	**Occupation**	Q4. How did you find the setup of the equipment?
1	14	SaLT	Fine – all practical / safe / ethical and with familiarity with the routine should work smoothly
	19	OT	Communication aids may need to be positioned closer for visual impairment
2	8	LSA	The set up was clear, and Mark explained that a longer pole was in the process of being made which would be more practical.
	12	OT	< Form not returned >
3	15	Teacher	< Form not returned >
	1	LSA	Frame used for curtain may get tangled in wheelchair wheels – not sure what else could be used.
Summary			
			• Address issues with pole

Question 5			
Group No.	**SP No.**	**Occupation**	Q5. Do you have any further suggestions or comments about how the assessment could be improved?
1	14	SaLT	No!
	19	OT	It may need to be done in 2 stages because of fatigue
2	8	LSA	< No answer given >
	12	OT	< Form not returned >
3	15	Teacher	< Form not returned >
	1	LSA	None.
Summary			
			• Split into 2 stages to allow for fatigue

Appendix D E-tran frame and symbols cards used

Figure D.1 E-tran frame with the symbols used for (some of) the physical touch assessments

For an explanation of E-tran frames please see:
http://www.communicationmatters.org.uk/page/e-tran-frames

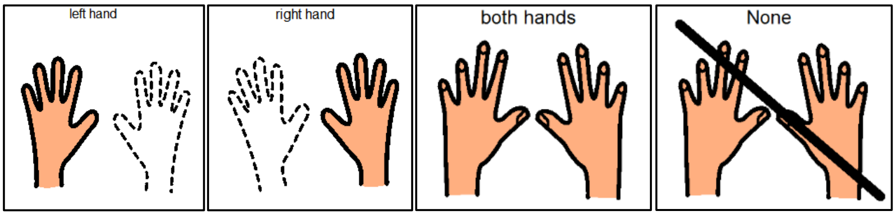
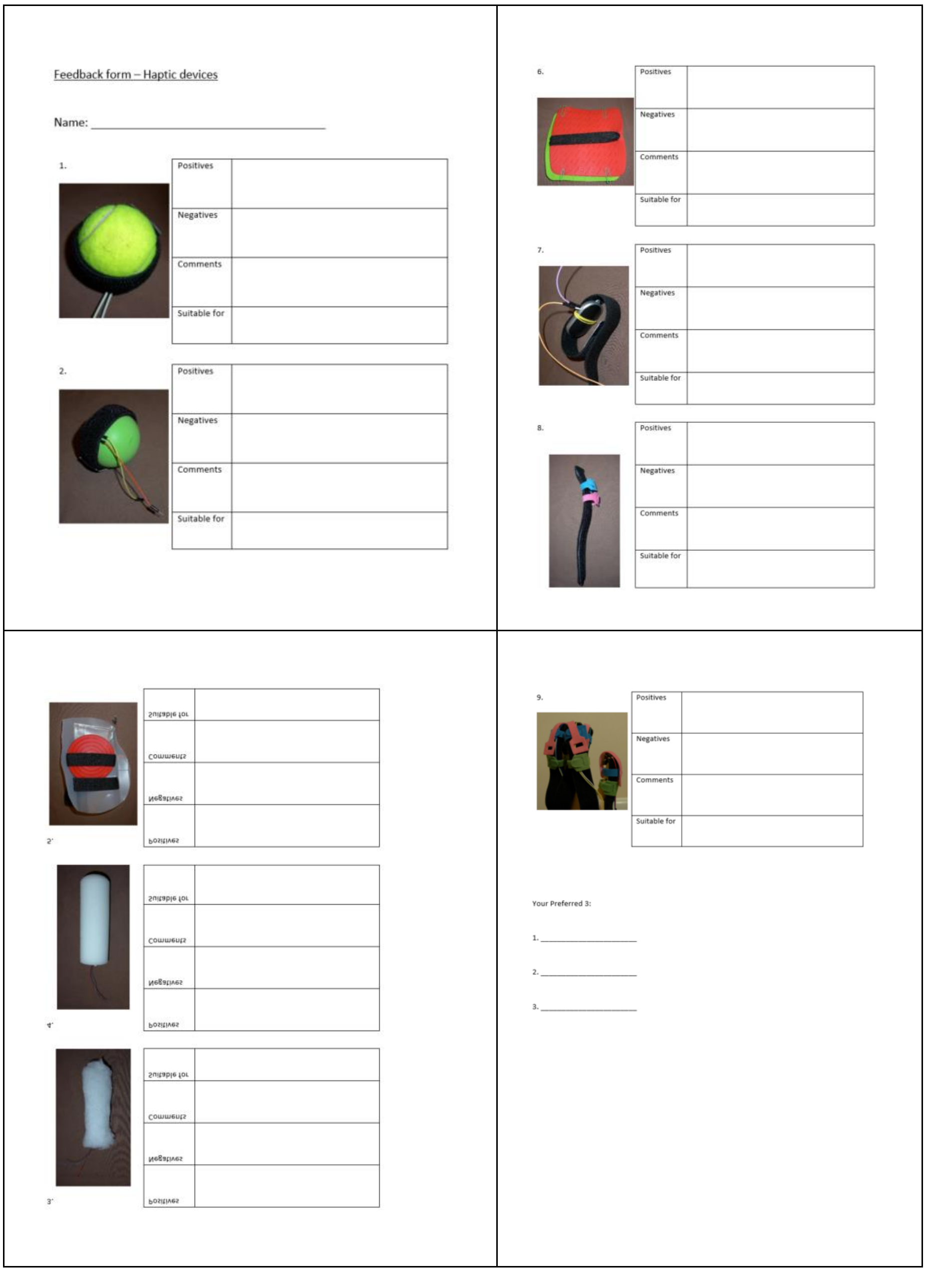


Figure D.2 The symbol cards used in the 'Physical' assessments

BoardMaker PCS symbols (Tobii Dynavox LLC 2018a)

Appendix E SP Trials: Round 1 - Haptic prototypes



Feedback form – Haptic devices

Name: ______________________________

1.

Positives	
Negatives	
Comments	
Suitable for	

2.

Positives	
Negatives	
Comments	
Suitable for	

6.

Positives	
Negatives	
Comments	
Suitable for	

7.

Positives	
Negatives	
Comments	
Suitable for	

8.

Positives	
Negatives	
Comments	
Suitable for	

3.

Positives	
Negatives	
Comments	
Suitable for	

4.

Positives	
Negatives	
Comments	
Suitable for	

5.

Positives	
Negatives	
Comments	
Suitable for	

9.

Positives	
Negatives	
Comments	
Suitable for	

Your Preferred 3:

1. ______________

2. ______________

3. ______________

Figure E.1 SP Trials: Haptic prototypes - feedback form

Table E.1 SP Trials: Collated answers from feedback forms

Prototype	Group No.	SP No.	Occupation/ Job role	Positives	Negatives	Comments	Suitable for
1. 	1	14	SaLT	Easy to attach/remove	Less powerful than 2. Not flexible so less comfortable Most info. seems to be in palm – not fingers/wrist.	↑noise – could be positive or negative (increased multisensory feedback or a distraction)	Those able to open fingers.
		19	OT	Easy to attach Simple design	Less vibration through hand. More localised in ball Potential limited finger involvement if unable to grip the ball. Can't wipe clean (would need to replace ball).	Rubberised ball gives greater vibration sensation & is more effective. May need additional straps	Most students except for those listed below (see device 2).
	2	8	LSA	Stays secure in palm of hand.	Difficult to use with students who have clenched fists. Rough feel. Noisy	< Nothing entered >	< Nothing entered >
		12	OT	Can be attached to palm + any fluctuating tone doesn't affect it.	Doesn't feel as secure. Less feedback when removing fingers, feels like a weaker sensation in palm.	< Nothing entered >	< Nothing entered >
	3	15	Teacher	If you can wrap your hand around the ball & get a "whole hand" experience	Wires. Ball is quite hard.	Hand stayed "fuzzy" for a period of time after taking it off.	Students who are older & able to close hand (i.e. to wrap around ball),
		1	LSA	Whole hand feeling	Ball too large.	< Nothing entered >	Good for good hand control Not good with involuntary movement
Summary							
				Easy to attach/remove. Whole hand feeling possible. Fits in palm.	Less powerful/vibration. Hygiene issues Rough/hard feel. May be too large, not appropriate for those who have clenched hands	The noise (from the vibration) may be a positive or a negative depending on the wearer/user. Residual effect	Good for those who have open fingers and are able to close hand around. Not so good for involuntary movement.

Prototype	Group No.	SP No.	Occupation/ Job role	Positives	Negatives	Comments	Suitable for
2. 	1	14	SaLT	Easy to attach/remove, comfortable. Size impacts on larger portion of hands/fingers. Sensation affects large area of hand.	May impact on palm only or palm + fingers or intermittent	Could vary size of ball for young children. Definite vibration on/off sensation	Students with poor hand control but able to open fingers. Those with athetoid/unintentional movements.
		19	OT	Easy to attach to hand & acceptable to student. Effective vibration sense. Can wipe clean	May not receive adequate sensation with fingers potentially not involved if student unable to position in grip	I like the simplicity of this one. Very acceptable for student to hold a ball May need additional straps	Most students except those with fixed deformity/contractures or sensory defensiveness.
	2	8	LSA	Comfortable to hold. Easier to grip. Quiet Stronger sensation	Difficult to get into clenched fists	< Nothing entered >	< Nothing entered >
		12	OT	More comfortable than previous one.	< Nothing entered >	< Nothing entered >	Students with variable tone.
	3	15	Teacher	Squishy ball – more comfortable.	Depends if student likes a deeper sensation. More intense.	Made my wedding ring vibrate too. More intense. More comfortable.	Students who have a tendency to have more involuntary movements. Students who need a deeper sensation.
		1	LSA	Feels stronger – feel right to end of fingers Feels 'nicer' squishy ball.	Very aware of fixings.	< Nothing entered >	Better for involuntary movement as easier to squash. Felt in scar tissue – possibly check if students have any injuries.
Summary							
				Easy to attach/remove. Stronger/larger area of sensation. Comfortable/nice feel/squishy. Good/easier grip. Quieter. Good hygiene - wipe clean.	Sensation may go mainly to palm not fingers. Difficult for those who have clenched hands. Strong sensation. Aware of fixings.	Could use different sized balls. Simple Clearly defined on/off. More intense.	Flexibility allows for involuntary movement/variable tone. Those who need a deeper sensation. Be careful with scar tissue (from injuries/operations etc.)

Prototype	Group No.	SP No.	Occupation/ Job role	Positives	Negatives	Comments	Suitable for
3. 	1	14	SaLT	Cosy! Flexible. Strong sensation.	Hygiene? Noisy (but could be +ve)	As 4 Main sensation in fingers when wrapped around it, then in palm	As 4
		19	OT	Nice texture – soft – student may/or may not like. Easy to apply.	Less vibration -? Dampened by soft fleece material.	As 4	As 4
	2	8	LSA	Good shape to get into fingers.	Less of a sensation	< Nothing entered >	< Nothing entered >
		12	OT	Good for students that have tight hands or have better movements at finger joints + tend to grip more with fingers then palm.	Tickles a little.	< Nothing entered >	< Nothing entered >
	3	15	Teacher	Soft to hold and comfy in hand.	Very localised “sensation” Could be resistant to “furry” texture.	< Nothing entered >	< Nothing entered >
		1	LSA	Nice fluffy feeling	Stronger pulse – possibly too much	< Nothing entered >	< Nothing entered >
Summary							
				Nice texture/flexible. Easy to fit Good for those who have tight hands.	Hygiene issues Less sensation, but stronger for one SP	Sensation mostly in fingers.	

Prototype	Group No.	SP No.	Occupation/ Job role	Positives	Negatives	Comments	Suitable for
4. 	1	14	SaLT	Variable vibration sensation when squeezed (inverse of what you'd expect)	Less easy to attach/remove Hygiene? Noisy (but could be +ve)	May need assistance to attach/remove to avoid hurting students' fingers. Main sensation in fingers.	Those who could only open fingers a little.
		19	OT	Easy to apply Able to vary the sensation – loosen grip = greater vibration. Sound feedback + this can also be varied by grip strength	Vibration only felt through fingers and not much through hand – may not be effective for those with reduced sensation.	May need strapping to maintain position in hand.	Many students Not suitable for those with reduced sensation which can be more evident in fingers.
	2	8	LSA	Moulds to a comfortable grip	Changes frequency of sensation through grip.	< Nothing entered >	< Nothing entered >
		12	OT	< Nothing entered >	When not gripping it feels more 'tickly' than gripping really tight.	< Nothing entered >	< Nothing entered >
	3	15	Teacher	Good to hold and better to hold.	May not like the texture of foam.	Very intense on fingers if solely in that position.	Students with minimal grasp.
		1	LSA	Nice to hold – easy to grip.	Stronger sensation – almost unpleasant	< Nothing entered >	Strong grip or some hand movement.
Summary							
				Inverse vibration – vibrates less when squeezed? Easy to apply. Feels nice. Good grip.	Less easy to attach/detach. Hygiene issues Noisy. Sensation mainly in fingers. Variable sensation	Strapping needed to maintain position. Intense on fingers.	Tight hands Minimal grasp/strong grip

Prototype	Group No.	SP No.	Occupation/ Job role	Positives	Negatives	Comments	Suitable for
5. 	1	14	SaLT	Good sensation over whole hand/fingers. Increased sensation + change in tone when squeezed	Less flexible Less easy to attach	If hand posture could be achieved gives regular sensation across whole hand	Requires open hand posture
		19	OT	Easy to hold More whole hand sensation. Vibration can vary with hand movement giving more feedback. Sound feedback too.	Device doesn't feel so secure and moves about. Thumb potentially not involved.	May be harder to apply to hand with spasticity	Students with resting hand posture without tone or spasticity or contractures.
	2	8	LSA	Quiet	Doesn't feel as secure.	< Nothing entered >	< Nothing entered >
		12	OT	< Nothing entered >	Relies on a student being able to get into a flat hand position.	< Nothing entered >	< Nothing entered >
	3	15	Teacher	Whole hand experience	Didn't like it as much as too much "sensory input"	Felt it in back of hand.	Students with open palm. Need a lot of support.
		1	LSA	Whole hand experience Feeling into back of hand through straps.	Straps need to be tight Holes needs fixing in middle.	< Nothing entered >	Better hand control – hand needs to be flatter – different sensation when clenched.
Summary							
				Whole hand sensation. Variable sensation depending on grip. Quiet. Some transference.	Less flexible. Not so secure. Needs an 'open' hand. Might be too much for some	Harder to attach to non-flat/open hands.	Requires open/flatter hand.

Prototype	Group No.	SP No.	Occupation/ Job role	Positives	Negatives	Comments	Suitable for
6. 	1	14	SaLT	Easy to clean Allows free movement of hand.	Hard to get contact with skin if not able to move Bit hot/sweaty! – not so comfortable	Feels bit awkward but if right shape/flexible texture could be good.	Open hand posture/athetoid movement
		19	OT	Continuous vibration sense with hand in all positions including fingers curling into tight grip.	Slips around a bit – not that secure	May need additional strapping & extra weight to get better contact with hand.	Students with flexibility & good range of movement as would be unable to apply and get skin contact for those with contracted hand position.
	2	8	LSA	All over sensation. Nice to grip, Good for students sensitive to vibration. Quiet	< Nothing entered >	< Nothing entered >	< Nothing entered >
		12	OT	Can forget it's there as it's light Less 'tickly' as it's whole hand	Might be harder to get onto a hand with high tone.	< Nothing entered >	< Nothing entered >
	3	15	Teacher	More tolerable. Good material to move.	Needed to put ball in centre to get the sensation.	Need to be shaped to get sensors in the correct position.	< Nothing entered >
		1	LSA	All over hand	Too strong for me – picked up a lot in scar tissue.	< Nothing entered >	Flatter hands – good control.
Summary							
				Good hygiene - easy to clean. Allows free hand movement. Even sensation. Quiet Flexible material. All over hand sensation.	Poor contact with skin. Can be hot/sweaty. Poor sensation – putting a ball in the middle helped. Too strong.	Needs to be shaped better.	Open/flatter hands. Involuntary movement.

Prototype	Group No.	SP No.	Occupation/ Job role	Positives	Negatives	Comments	Suitable for
7. 	1	14	SaLT	Allows freedom of movement. Unobtrusive. Most natural feeling so far! Positive sensation – strong	Slightly more fiddly to attach. Less finger sensation – mostly palm. No variation in feedback when gripped	< Nothing entered >	Nearly all – anyone who was able to open hand enough to attach it
		19	OT	Increased hand freedom. Much greater vibration sense Easy to apply Secure fit.	No finger involvement	I feel the sensory feedback is much greater & more obvious with this device.	Nearly all students.
	2	8	LSA	Majority of student would easily use this.	< Nothing entered >	< Nothing entered >	< Nothing entered >
		12	OT	Less invasive. Easy to put on.	< Nothing entered >	< Nothing entered >	< Nothing entered >
	3	15	Teacher	Strong sensation in palm.	No sensation on fingertips Difficult to put onto a student.	Could change the sensation so that you can channel feeling into finger.	< Nothing entered >
		1	LSA	Small + easy to hold Very localised vibration (Pos + neg)	< Nothing entered >	< Nothing entered >	< Nothing entered >
Summary							
				Allows freedom of movement. Natural feeling Easy to apply/fit. Secure fit Strong sensation Small	May be more difficult to attach. Little/no finger sensation.	Greater/more obvious sensory feedback.	Nearly all students. Anyone with hands that can open enough to attach it.

Prototype	Group No.	SP No.	Occupation/ Job role	Positives	Negatives	Comments	Suitable for
8. 	1	14	SaLT	Easy to get on/off Direct sensation to fingers	Duller – less direct sensation Less secure on your finger which made me move less – to stop it coming off	Less transfer of sensation than no. 9	Those able to move fingers/open hands
		19	OT	Easy to fit & feels secure Obvious vibration sense Comfortable	May be difficult to apply to unusual hand posture	Looks appealing and fun colours. Could add characters to Velcro straps to appeal to younger students.	Those with good range of movement in thumb and index finger.
	2	8	LSA	Strong sensation Soft material	< Nothing entered >	< Nothing entered >	< Nothing entered >
		12	OT	Intense vibration easy to pick up.	More fussy to put on Might not stay in place.	< Nothing entered >	< Nothing entered >
	3	15	Teacher	Very powerful	< Nothing entered >	Cold sensation afterwards!!!	Students who need fine prescriptive sensation.
		1	LSA	Love the idea of having fingertip sensation but far too intense needs to be much less	< Nothing entered >	< Nothing entered >	Students with good hand control
Summary							
				Easy to attach / detach. Secure. Comfortable, soft material Direct / obvious / strong / intense / powerful sensation. Too intense for SP1.	Duller sensation Less secure. May be difficult to attach	Appealing/fun appearance. Could be customised for younger students. Residual sensation (cold)	Those with control of hands and digits.

Prototype	Group No.	SP No.	Occupation/ Job role	Positives	Negatives	Comments	Suitable for
9. 	1	14	SaLT	Intense/direct delivery of the sensation. Transfer of sensation to rest of the hand. Very 'obvious' sensation. Allows movement	Fiddly (possibly) to apply, although actually easier than it looked	Good/positive sensation	Person with mobility in fingers, able to open hand. NOTE: Only used finger and thumb version
		19	OT	Easy to apply to relaxed hand position. The most vibration sense – direct contact with skin. Felt throughout hand. Good contact.	Would be difficult to apply to more unusual hand posture or increased tone Less secure	The sensory feedback is very clear & obvious. May be too much for some students with hypersensitivity/sensory defensiveness	Sensory seeking students who benefit from increased vibration sense. Students with reasonable range of movement in thumb & index finger. NOTE: Only used finger and thumb version
	2	8	LSA	Feel sensation in all fingers and clearly defined. Easily adjustable	May be difficult to put on and keep on some students	< Nothing entered >	More able students
		12	OT	Felt secure + in the right place, + whole hand feedback not just one place in hand	Might be 'faffy' to put on.	< Nothing entered >	< Nothing entered >
	3	15	Teacher	Better sensation throughout the whole finger. Quickly adjustable.	Perhaps a bit tricky to get on.	The best one for the task as a genuine feeling personalised to each finger.	Students who have good finger dexterity.
		1	LSA	Both fingers stimulated – better than singular.	Strong feeling – maybe too strong.	< Nothing entered >	< Nothing entered >
Summary							
				Intense/direct sensation Transferred to rest of the hand. Allows movement. Good contact/secure Adjustable	May be difficult to attach and keep on. Less secure. Strong sensation	Strong/clear sensation. Might be too much for some. Personalised to each finger.	Good mobility/dexterity in fingers. Sensory seeking students who need stronger sensation. More able students.

Appendix F SP Trials: Haptic prototypes 7 and 9

Physical Touch or Haptic Feedback (Hands) Assessment Answers

Participant's Name: ______________________ Physical touch / Haptic feedback

Date: _____________ Time: _________ Baseline / Outcome

Trial Number	Hand stimulated	Participant's response	Correctly identified		
1	Left		Yes		No
2	Right		Yes		No
3	Right		Yes		No
4	Left		Yes		No
5	None		Yes		No
6	Right		Yes		No
7	Both		Yes		No
8	None		Yes		No
9	Left		Yes		No
10	Both		Yes		No
11	Left		Yes		No
12	None		Yes		No
13	Both		Yes		No
14	Right		Yes		No
15	None		Yes		No
16	Both		Yes		No
17	None		Yes		No
18	Left		Yes		No
19	Both		Yes		No
20	Right		Yes		No

Figure F.1 SP Trials: Form for trials with haptic prototype 7 (hands)

Actual Assessment Answers

Participant's Name: ____________________________ Date: ___________ Time: __________

Participant's hand: ________________________

Trial Number	Hand	Digit	Participant's response	Correctly identified		
1	Left	Thumb		Yes		No
2	Right	Little		Yes		No
3	Right	Ring		Yes		No
4	Left	None		Yes		No
5	None	Middle		Yes		No
6	Right	Index/Forefinger		Yes		No
7	Both	Middle		Yes		No
8	None	Index/Forefinger		Yes		No
9	Left	Thumb		Yes		No
10	Both	None		Yes		No
11	Left	Little		Yes		No
12	None	Ring		Yes		No
13	Both	Ring		Yes		No
14	Right	Little		Yes		No
15	None	Thumb		Yes		No
16	Both	None		Yes		No
17	None	Middle		Yes		No
18	Left	Index/Forefinger		Yes		No

Figure F.2 SP Trials: Form for trials with haptic prototype 9 (fingers)

Haptic prototypes 7 and 9 trials (Results)

Table F.1 shows the results of the SP trials of haptic prototype 7. Table F.2 shows the results of the SP trials of haptic prototype 9.

Prototype 7 was designed to send a haptic sensation predominantly to the palm of the hand. Trials were to determine if the wearer could discriminate between the sensation being sent to one hand, neither hand, or both hands. A total of 20 trials were carried out with each SP (see Figure F.1). This involved 5 sets of 4 of each of: 1). left hand only, 2). right hand only, 3). both hands, 4). neither hand.

Prototype 9 was designed to send haptic sensations to the front of the tips of individual digits. Trials involved only the SPs dominant hand and sensations were delivered to one or none of their five digits (see Figure F.2). A total of 18 trials were carried out with each SP. This involved three sets of six of each of: 1). thumb only, 2). index/forefinger only, 3). middle finger only, 4). ring finger only, 5). little finger only, 6). no digit.

Table F.1 Results of haptic detection trials (Prototype 7)

SP		**Scores**
SP No.	SP Handedness (Dominant hand)	Prototype 7 'Pebble' (both hands used)
14	Right	20/20
19	Right	20/20
8	Left	20/20
12	Right	20/20
15	Right	20/20
1	Right	20/20

Table F.2 Results of haptic detection trials (Prototype 9)

SP		**Scores**	
SP No.	SP Handedness (Dominant hand)	Prototype 9 'Glove' (Single hand only)	
14	Right	N/A	
19	Right	N/A	
8	Left	18/18	Left hand
12	Right	18/18	Right hand
15	Right	18/18	Right hand
1	Right	18/18	Right hand

Appendix G SP Trials: Round 2 - Haptic prototype 7

Vibration motor spin speeds and start/stop behaviours

Table G.1 SP Trials: Haptic vibration motor spin speeds and spin up and spin down / start / stop behaviours

Date	**Time**	**SP No.**	**Occupation**	**Dominant hand**	**Left hand**		**Right hand**		**Speed**	
					Preferred sensation behaviour	**Preferred speed**	**Preferred sensation behaviour**	**Preferred speed**	**On**	**Off**
23/03/17	15:00	14	SaLT	Right	2 (Definitely)	175	2	175	000 175	000 000
23/03/17	15:00	17	Teacher	Left	1	175	2	150	000 175	175 000
23/03/17	15:30	19	Teacher	Right	1	175	1	175	000 175	175 000
23/03/17	15:30	7	SaLT	Left	2	175	2	175	000 175	000 000
23/03/17	15:30	8	LSA	Left	1	255 (Pupil 175)	1	175	000 255	255 000
24/03/17	10:00	27	Physiotherapist	Right	1	150	1	255	000 255	255 000
24/03/17	11:00	1	LSA	Right	3	175	3	100	100 100	000 000
24/03/17	11:00	6	Teacher	Right	2	150	2	175	000 150	000 000
Totals				N = 8 Right = 5 Left = 3	**1** (Fade in, fade out) **= 4** **2** (Fade in, immediate stop) **= 3** **3** (Immediate start and stop) **= 1**	150 = 2 175 = 5 255 = 1	**1** (Fade in, fade out) **= 3** **2** (Fade in, immediate stop) **= 4** **3** (Immediate start and stop) **= 1**	100 = 1 150 = 1 175 = 5 255 = 1		

Round 2 – Session 1 – Haptic prototype 7 only

SP Questionnaire (Form)

Haptic feedback device – Feedback form

Name: ________________ Date & Time: __________ Code: ____________

How did the sensation feel?

How was the fit of the haptic device?

Do you think that it will be suitable for the Target Group that the researcher described?

Other comments:

Thank you

Mark

Figure G.1 SP Trials: Haptic prototype 7 - questionnaire

Round 2 – Session 1 – Haptic prototype 7 only: SP Questionnaire (Answers)

Table G.2 SP Trials: Haptic prototype 7 questionnaire (Answers)

Question 1. How did the sensation feel?

Group No.	**SP No.**	**Occupation**	Question How did the sensation feel?
1	14	SaLT	Ramping was good – had no sense of "shock" or sudden start, so hopefully this will inhibit startle response. Comfortable. Definite + defined, but not too intense. Focussed my attention on my hand.
	17	Teacher	Buzzing/fizzy (Didn't love the buzzy feeling!) (Slightly tickled).
2	19	Teacher	Rather like holding an electronic fan Slightly tickly, not unpleasant Rather a 'halting' fade in
	7	SaLT	Sensation was comfortable and remained even when it had ended.
	8	LSA	Comfortable, fade in fade out sensation prepared me for what was coming and didn't startle me.
3	27	Physiotherapist	Comfortable but more irritating as the motor speed increased. Too slow didn't create enough feedback.
4	1	LSA	Relaxed and interesting.
	6	Teacher	A bit buzzy but OK. Preferred the slower speed – but I don't like buzz vibration much (electric toothbrushes yuk) Lots of students love vibrations.
Summary			
			• Some liked fade in, fade out/ramping sensation • Focussed attention on hand • Some didn't like the vibration, tickling • One SP experienced residual sensation • Lots of students like vibration

Question 2. How was the fit of the haptic device?

Group No.	**SP No.**	**Occupation**	Question How was the fit of the haptic device?
1	14	SaLT	Comfortable I was concerned that the sensation of the Velcro strap would be a distraction, but once the haptic feedback started I wasn't aware of the strap at all.
	17	Teacher	Good/comfortable
2	19	Teacher	Snug + comfortable
	7	SaLT	Comfortable. Fits nicely in the palm of hand + cable was unobtrusive.
	8	LSA	Device again felt comfortable and lightweight and didn't restrict hand movement.
3	27	Physiotherapist	Comfortable at the base of the thumb Sitting in the palm.
4	1	LSA	Fitted well after adjustment. Felt comfortable after time to get used to it.
	6	Teacher	Felt a bit tight initially, preferred it looser. Wires a bit annoying
Summary			
			• Most found it a good and comfortable fit • Didn't restrict hand movement

Question 3. Do you think that it will be suitable for the Target Group that the researcher described?

Group No.	SP No.	Occupation	Question Do you think that it will be suitable for the Target Group that the researcher described?
1	14	SaLT	Yes
	17	Teacher	Yes, strength of buzz will need to vary?
2	19	Teacher	Probably, but may need to be made smaller for a young child's palm.
	7	SaLT	Yes – they may need some support to get used to the fit + sensation
	8	LSA	Yes, should be easy to attach. I think the fade in, fade out sensation would be most suitable.
3	27	Physiotherapist	Yes – position may need checking during longer periods of use as the thumb may adduct (move inwards) and take device 'off contact' of palm.
4	1	LSA	Yes, with attention to fit (tightness) Remember to have wires tucked away. More Velcro cross over to avoid being able to knock off.
	6	Teacher	Yes
Summary			
			• Most thought it suitable for the TG • Easy to attach

Question 4. Other comments

Group No.	SP No.	Occupation	Question Other comments:
1	14	SaLT	"Stronger" seemed to be actually smoother. The slower vibration was more wobbly + felt less stable/regular.
	17	Teacher	< Nothing entered >
2	19	Teacher	< Nothing entered >
	7	SaLT	< Nothing entered >
	8	LSA	< Nothing entered >
3	27	Physiotherapist	Post use stimulation may indicate sensitivity to device.
4	1	LSA	None.
	6	Teacher	- Fingerless mesh gloves?
Summary			
			• Stronger sensation was smoother • Some may be sensitive to device

Appendix H NASA-TLX (Form)

Source: https://humansystems.arc.nasa.gov/groups/TLX/downloads/TLXScale.pdf

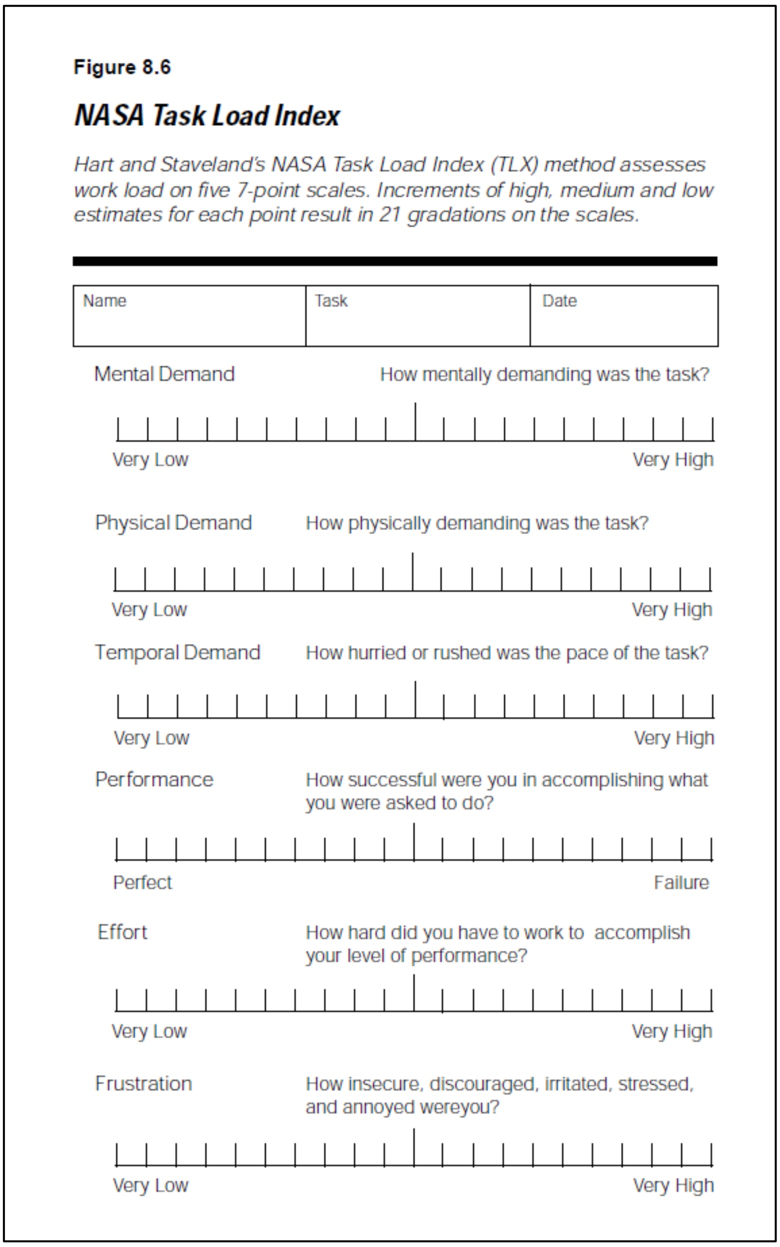


Figure 8.6

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

* Paper and pencil version

NASA-TLX (National Aeronautics and Space Administration (NASA) 2019) is a subjective rating scale of perceived workload. It contains the rating scale shown above and also has a 'weightings' component which allows subjects to attach greater importance to particular subscales, depending upon which they considered contributed most to the task workload.

Only the ratings scale was used in this study. The weightings element was omitted, as the intention was to identify which subscales had the highest ratings rather than the relative importance of the subscales themselves and to simplify the evaluation process.

Appendix I SP Trials: NASA-TLX scores – All task groups

'Cubes': One NASA-TLX form was completed for the whole stage. Average of all SP scores.

Table I.1 SP Trials: 'Cubes' - NASA-TLX Scores – All SPs – Arithmetic mean

Q.	Sub-scale	Range	Arithmetic mean (n = 6)
1	***Mental Demand***	0 = Very Low 100 = Very High	27
2	***Physical Demand***	0 = Very Low 100 = Very High	17
3	***Temporal Demand***	0 = Very Low 100 = Very High	15
4	***Performance***	0 = Perfect 100 = Failure	19
5	***Effort***	0 = Very Low 100 = Very High	18
6	***Frustration***	0 = Very Low 100 = Very High	15

'Directions': One NASA-TLX form was completed for each task. Averaged by task number.

Table I.2 SP Trials: 'Directions' - NASA-TLX Scores – All SPs – Arithmetic mean

Q.	Subscale	Range	Challenges (Arithmetic mean) (n = 7)					Averaged
			1	2	3	4	5	
			(Left/ Right)	(Forwards/ Backwards)	(Left, Right, Forwards & Backwards)	(Left, Right, Up & Down)	(All Controls)	
1	**Mental Demand**	0 = Very Low 100 = Very High	34	16	31	24	34	28
2	**Physical Demand**	0 = Very Low 100 = Very High	30	15	19	16	17	19
3	**Temporal Demand**	0 = Very Low 100 = Very High	14	13	13	15	13	14
4	**Performance**	0 = Perfect 100 = Failure	19	18	21	11	19	18
5	**Effort**	0 = Very Low 100 = Very High	39	25	33	26	33	31
6	**Frustration**	0 = Very Low 100 = Very High	15	26	24	16	18	20

5 tasks, each carried out by seven SPs: 17, 8, 7, 19, 27, 1, 6

Scores averaged by task and subscale

Example: Task 1 (Left/Right), Mental demand = 7 subscales added together (1 for each SP) / 7

'Scenarios': One NASA-TLX form was completed for the whole stage. Average of all SP scores.

Table I.3 SP Trials: 'Scenarios' - NASA-TLX Scores – All SPs – Arithmetic mean

Q.	Sub-scale	Range	Arithmetic mean (n = 7)
1	***Mental Demand***	0 = Very Low 100 = Very High	59
2	***Physical Demand***	0 = Very Low 100 = Very High	30
3	***Temporal Demand***	0 = Very Low 100 = Very High	29
4	***Performance***	0 = Perfect 100 = Failure	17
5	***Effort***	0 = Very Low 100 = Very High	56
6	***Frustration***	0 = Very Low 100 = Very High	32

Appendix J System Usability Scale (SUS) (Form)

Source: Brooke (1996)

System Usability Scale

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the system	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

Appendix K SP Trials: System Usability Scale (SUS) scores – all task groups

'Cubes':

Table K.1 SP Trials: 'Cubes' - Individual SUS Scores

SP No.	SUS score (Out of 100)
14	---
17	82.5
8	82.5
7	92.5
19	65
27	---
1	87.5
6	62.5

Number of SPs who attempted the task = 6. Arithmetic mean = 79 (A higher SUS score is preferable i.e. closer to 100)

Table K.2 SP Trials: 'Cubes' - Collated SUS results

	Question	Comments
1.	I think that I would like to use this system frequently	A spread of answers. This is perhaps an inappropriately phrased question for the SPs as they have no need to use such a system. It may have been better to have rephrased the question with the emphasis on the TG
2.	I found the system unnecessarily complex	6/6 Answered towards the 'Strongly disagree' end of the scale
3.	I thought the system was easy to use	4/6 Answered 'Strongly agree' SP17 answered 'Strongly disagree' which was in conflict with their answer to Feedback form Q3. 'Did you experience any difficulties or things that didn't make sense to you?' which was 'No – it seemed straight forward'
4.	I think that I would need the support of a technical person to be able to use this system	4/6 Answered towards the 'Strongly disagree' end of the scale
5.	I found the various functions in this system were well integrated	4/6 Answered towards the 'Strongly agree' end of the scale
6.	I thought there was too much inconsistency in this system	5/6 Answered towards the 'Strongly disagree' end of the scale
7.	I would imagine that most people would learn to use this system very quickly	6/6 Answered 'Strongly agree'
8.	I found the system very cumbersome to use	5/6 Answered towards the 'Strongly disagree' end of the scale
9.	I felt very confident using the system	6/6 Answered towards the 'Strongly agree' end of the scale
10.	I needed to learn a lot of things before I could get going with this system	6/6 Answered towards the 'Strongly disagree' end of the scale

'Directions':

Table K.3 SP Trials: 'Directions' - SUS results

SP No.	SUS score (Out of 100)
14	---
17	92.5
8	77.5
7	70
19	62.5
27	55
1	85
6	57.5

Number of SPs who attempted the task = 7. Arithmetic mean = 71 (A higher SUS score is preferable i.e. closer to 100)

Table K.4 SP Trials: 'Directions' - SUS results – analysis by question

	Question	Comments
1.	I think that I would like to use this system frequently	A spread of answers. This is perhaps an inappropriately phrased question for the SPs as they have no need to use such a system. It may have been better to have rephrased the question with the emphasis on the TG
2.	I found the system unnecessarily complex	7/7 answered towards the 'Strongly disagree' end of the scale
3.	I thought the system was easy to use	6/7 answered towards the 'Strongly agree' end of the scale
4.	I think that I would need the support of a technical person to be able to use this system	The scores were mixed. This is perhaps attributable to the technical issues which sometimes occurred during trials
5.	I found the various functions in this system were well integrated	5/7 answered towards the 'Strongly agree' end of the scale
6.	I thought there was too much inconsistency in this system	5/7 answered towards the 'Strongly disagree' end of the scale
7.	I would imagine that most people would learn to use this system very quickly	6/7 answered towards the 'Strongly agree' end of the scale
8.	I found the system very cumbersome to use	6/7 answered towards the 'Strongly disagree' end of the scale
9.	I felt very confident using the system	5/7 answered towards the 'Strongly agree' end of the scale
10.	I needed to learn a lot of things before I could get going with this system	6/7 answered towards the 'Strongly disagree' end of the scale

'Scenarios':

Table K.5 SP Trials: 'Scenarios' - SUS results

SP No.	SUS score (Out of 100)
14	---
17	90
8	85
7	62.5
19	65
27	52.5
1	80
6	47.5

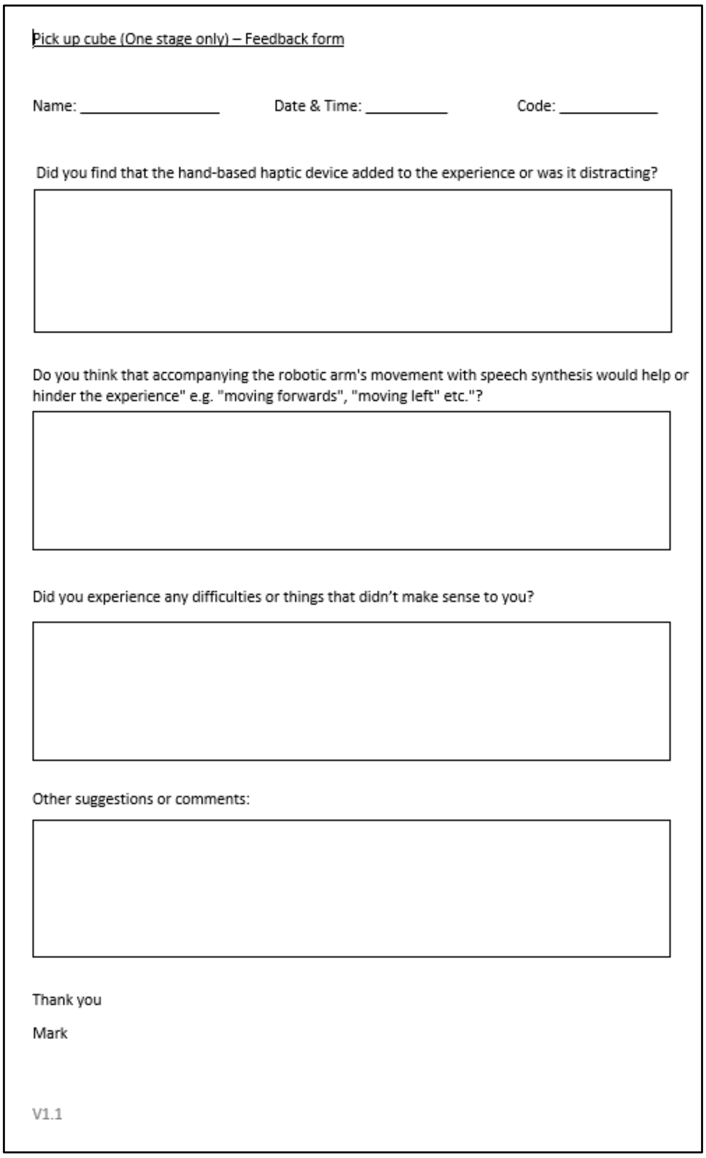
Number of SPs who completed task = 7. Arithmetic mean of scores = 72 (A higher SUS score is preferable i.e. closer to 100).

Table K.6 SP Trials: 'Scenarios' - SUS results – collated by question

	Question	Comments
1.	I think that I would like to use this system frequently	A spread of answers. This is perhaps an inappropriately phrased question for the SPs as they have no need to use such a system. It may have been better to have rephrased the question with the emphasis on the TG
2.	I found the system unnecessarily complex	5/7 Answered towards the 'Strongly disagree' end of the scale
3.	I thought the system was easy to use	5/7 Answered towards the 'Strongly agree' end of the scale
4.	I think that I would need the support of a technical person to be able to use this system	Ambiguity in question - is technical support for set up, or for them to use the system?
5.	I found the various functions in this system were well integrated	6/7 Answered towards the 'Strongly agree' end of the scale
6.	I thought there was too much inconsistency in this system	4/7 Answered towards the 'Strongly disagree' end of the scale - technical issues?
7.	I would imagine that most people would learn to use this system very quickly	5/7 Answered towards the 'Strongly agree' end of the scale
8.	I found the system very cumbersome to use	5/7 Answered towards the 'Strongly disagree' end of the scale
9.	I felt very confident using the system	5/7 Answered towards the 'Strongly agree' end of the scale
10.	I needed to learn a lot of things before I could get going with this system	6/7 Answered towards the 'Strongly disagree' end of the scale

Appendix L SP Trials: Intervention task groups: SP Questionnaires

Round 2 - Session 2 - ‘Cubes’ (Form)



Pick up cube (One stage only) – Feedback form

Name: ________________ Date & Time: __________ Code: ____________

Did you find that the hand-based haptic device added to the experience or was it distracting?

Do you think that accompanying the robotic arm's movement with speech synthesis would help or hinder the experience" e.g. "moving forwards", "moving left" etc."?

Did you experience any difficulties or things that didn’t make sense to you?

Other suggestions or comments:

Thank you

Mark

V1.1

Figure L.1 SP Trials: Intervention - 'Cubes' - questionnaire

Round 2 - Session 2 - ‘Cubes’ (Answers)

Table L.1 SP Trials: Intervention - ‘Cubes’ - Questionnaire

Group No.	SP No.	Occupation	Question (1). Did you find that the hand-based haptic device added to the experience or was it distracting?
1	*14	SaLT	< Didn’t do this part >
	17	Teacher	It added to the experience. Helped me to focus.
2	19	Teacher	Added to it – would feel more ‘relevant’ if it was a sensation of pressure in my fingers rather than a ‘buzz’, but I am looking at it from the point of view of someone who has use of my hand.
	7	SaLT	Added to the experience – it was not distracting. I think having some experience previously made it less novel therefore less distracting.
	8	LSA	Added to the experience – reinforced in my mind that I was picking up the block.
3	27	Physiotherapist	< Unable to take part in this part >
4	1	LSA	Liked having the sensation when something happened I would prefer it to vibrate more on pick up/release and less when just holding (if this were possible).
	6	Teacher	I didn’t really like it – don’t like buzzing – possibly prefer on fingers – less tickly. It surprised me when it came on!
Summary			
			• Most thought the haptic device added to the experience • A haptic sensation involving pressure may be better • Some didn’t like the haptic sensation

Group No.	SP No.	Occupation	Question (2). Do you think that accompanying the robotic arm's movement with speech synthesis would help or hinder the experience" e.g. "moving forwards", "moving left" etc."?
1	*14	SaLT	When you first mentioned it I thought that having speech commenting on the movement would be helpful, but having seen it I'm not sure. I think the movements are too complex to describe accurately and it could just be an overload of information. I'd probably opt not to have it.
	17	Teacher	I thought that it would be good initially to have the speech reinforcement then once the student understands the movement that it could be taken away.
2	19	Teacher	Would not like a verbal commentary to accompany the action of the arm – liked the quiet concentration time.
	7	SaLT	Giving auditory feedback of direction may be distracting but if used as a teaching tool would be good to help with learning.
	8	LSA	I think students may find speaking ‘left’ ‘right’ a distraction to begin with but perhaps there could be an option to add these as they gain confidence.
3	27	Physiotherapist	< Unable to take part in this part >
4	1	LSA	Having the vocal prompts is a good thing and great for reinforcing the positional words.
	6	Teacher	Variable – not necessary in this task – but possibly interesting with more complex instructions – and for bit by bit instructions – direct control.
Summary			
			• Some felt that it would not add value, whereas others did. It depends on the activity and mode of operation

Group No.	SP No.	Occupation	Question
			(3). Did you experience any difficulties or things that didn't make sense to you?
1	*14	SaLT	< Didn't do this part >
	17	Teacher	No – it seemed straight forward
2	19	Teacher	Seeing the black arm against the black cloth was a little difficult.
	7	SaLT	Haptic sensor continued to stay on when block had been dropped.
	8	LSA	Haptic sensation started and finished a little too early.
3	27	Physiotherapist	< Unable to take part in this part >
4	1	LSA	None
	6	Teacher	Problem calibrating glasses – quite disturbing doing it without them. Not used to eye gaze and found it hard to keep head still & just use eyes.
Summary			
			• Hard to see the black robotic arm against the black background • Some haptic device timing issues

Group No.	SP No.	Occupation	Question
			(4). Other suggestions or comments:
1	*14	SaLT	< Didn't do this part >
	17	Teacher	I think, I would like the sensation to end when the cube is dropped.
2	19	Teacher	< No comment >
	7	SaLT	I think the speed was good but the initiation of movement could have been a little quicker, less of a pause.
	8	LSA	I found the different viewpoints useful.
3	27	Physiotherapist	< Unable to take part in this part >
4	1	LSA	If trying to pick up a cube that's not there, it could stop when realises nothing there?
	6	Teacher	White background for cubes so arm more visible? (Being picky!)
Summary			
			• The two different viewpoints were useful • Change background to make cubes more visible

* SP14 Did not use the system – they only observed SP17 using it

Round 2 - Session 3 - 'Directions' – 'Towers' (Form)

Session 3 - Towers – Feedback form

Name: ________________ Date & Time: __________ Code: ____________

1. After last week's session, did you experience any after-effects e.g. headaches or sensations in your hand?

2. When directing the robot arm today, could you see what you were doing? Were you able to work out where the robotic arm was relative to the tower?

3. Did you experience any difficulties or things that didn't make sense to you?

4. Other suggestions or comments:

Thank you

Mark

Session 3 - Feedback form - Towers v1.0.docx

Figure L.2 SP Trials: Intervention - 'Directions' – 'Towers' – questionnaire (Form)

Round 2 - Session 3 - 'Directions' – 'Towers' (Answers)

Table L.2 SP Trials: Intervention 'Directions' – 'Towers' – questionnaire (collated answers)

Group No.	**SP No.**	**Occupation**	Question 1. After last week's session, did you experience any after-effects e.g. headaches or sensations in your hand?
1	*14	SaLT	No after effects
	17	Teacher	No
2	19	Teacher	no
	7	SaLT	For a small while after session I felt aware of my hand – the feeling was not uncomfortable or distressing.
	8	LSA	No
3	27	Physiotherapist	No ongoing effect
4	1	LSA	None
	6	Teacher	No
Summary			
			• One SP reported greater awareness of their hand for a time, but without adverse effects

Group No.	**SP No.**	**Occupation**	Question 2. When directing the robot arm today, could you see what you were doing? Were you able to work out where the robotic arm was relative to the tower?
1	*14	SaLT	Yes – easy to look between the live action and the screens.
	17	Teacher	Once it started I could, but on the first instruction I couldn't see the arm. I used the screen all the time, so for me the 1st mvmt (?movement) guessed the direction from memory.
2	19	Teacher	Yes – but needed to look at both screen + real objects, especially when deciding whether to move forwards/backwards or up/down.
	7	SaLT	Yes, @ times I used both the screen + real life perspective.
	8	LSA	Yes, it was very helpful having two angles.
3	27	Physiotherapist	Some slight confusion from looking at the screen and then having a clear visual field of the actual model. May have benefited from moving the model nearer.
4	1	LSA	Was fun working it out. with practice was able to demolish tower. Slightly harder as wearing glasses this week (RESEARCHER NOTE: usually wears contact lenses).
	6	Teacher	It was a bit of a struggle – Would have liked a birds eye view – If with student would have wanted to show them from the other side. I tried to do it without glancing across, and just using screen but not obvious with later challenges.
Summary			
			• Some SPs found this easier than others • It was suggested that a bird's eye view might help

Group No.	SP No.	Occupation	Question
			3. Did you experience any difficulties or things that didn't make sense to you?
1	*14	SaLT	No From where I was sitting – The robotic arm movements were not as 'pure' as I'd anticipated e.g 'forwards' was also slightly 'down', but minor effect!
	17	Teacher	No it was very straight forward. Only thing was not seeing the bricks on the screen initially.
2	19	Teacher	Technical issues
	7	SaLT	No
	8	LSA	Robotic arm reached movement limitations (going down) but this was easily resolved by choosing a different movement.
3	27	Physiotherapist	Some problems with the technical aspect.
4	1	LSA	Slight problems with calibration this week (see above) All made sense.
	6	Teacher	I was so caught up in the sitting still and trialling it, I forgot what I needed to do, and gazed at wrong icons at times. I needed to say what I intended out loud. A little frustrating at the arm not going as low as I would have liked.
Summary			
			• Some technical issues encountered • Some limitations to the robot arm's movements

Group No.	SP No.	Occupation	Question
			4. Other suggestions or comments:
1	*14	SaLT	Mute the sounds with table cloth/felt but don't eliminate them as you become more tolerant + it adds to the anticipation. May colour the pincers to make it more obvious which bit should contact the tower
	17	Teacher	Could the arrows be on the same screen as the view of the arm? The bricks were initially very noisy – with all of them falling on a hard surface (got used to it)
2	19	Teacher	n/a
	7	SaLT	< Nothing entered >
	8	LSA	< Nothing entered >
3	27	Physiotherapist	Understand the need for a really good visual understanding of the model.
4	1	LSA	At the extremes sometimes 'good view' wasn't achievable.
	6	Teacher	I'd like to try hitting a hanging chime instrument with it!
Summary			
			• Make the table surface 'quieter' • Colour the gripper to make it stand out more • Combine camera view and interface controls

* SP14 Did not use the system – they only observed SP17 using it

Round 2 - Session 4 - 'Scenarios' (Form)

Session 4 - Scenarios – Feedback form

Name: ________________ Date & Time: __________ Code: ____________

1. Do you consider this to be an appropriate activity for the target group in terms of difficulty etc.?

2. When directing the robot arm today, could you see what you were doing? Were you able to work out where the robot arm was relative to the ship and what you were trying to do?

3. Did you experience any difficulties or things that didn't make sense to you?

4. Other suggestions, improvement or comments:

Thank you

Mark

Session 4 - Feedback form - v1.0.docx

Figure L.3 SP Trials: Intervention - 'Scenarios' – questionnaire (Form)

Round 2 - Session 4 - 'Scenarios' (Answers)

Table L.3 SP Trials: Intervention - 'Scenarios' – questionnaire (collated answers)

Group No.	**SP No.**	**Occupation**	Question 1. Do you consider this to be an appropriate activity for the target group in terms of difficulty etc.?
1	*14	SaLT	Yes. Highly engaging + motivating. Fun!
	17	Teacher	Yes, it is challenging but it can be accomplished.
2	19	Teacher	Yes. Good fun and age appropriate for junior pupils.
	7	SaLT	Yes, very engaging & interesting. It will be something they have not ever had the opportunity to do before. Quite a big cognitive load however.
	8	LSA	Yes, it is fun and has been set up nicely. They would find it exciting when reaching attack and feel satisfied afterwards. The voice helps motivation.
3	27	Physiotherapist	Yes. It creates a 'sensation of interaction' even though the actual feel of the haptic feedback was inconsistent with the command.
4	1	LSA	Excellent for problem solving. I'm looking forward to seeing how participants work it out
	6	Teacher	Yes for level 2 etc. (I'd be interested in eye gaze for my lower ability, but too many steps for them!)
Summary			
			• Appropriate and within the TG's abilities

Group No.	**SP No.**	**Occupation**	Question 2. When directing the robot arm today, could you see what you were doing? Were you able to work out where the robot arm was relative to the ship and what you were trying to do?
1	*14	SaLT	Need different camera angles, but I don't feel this is a problem, as it is <u>real</u> + helps development of judgement over height/distance etc. from a fixed point.
	17	Teacher	Yes, I could see what I was doing, Yes, I could work out where I needed to place the robotic arm, but it was really good to have 'ask the robot'.
2	19	Teacher	Left & right were easier than up & down (depth). Using the real scene helped with this.
	7	SaLT	@ times I had to move my head to see where the arm was but generally this was very good.
	8	LSA	At times I had to move head forward to see a different angle. However having both camera and real life angles is very helpful.
3	27	Physiotherapist	Mostly. I needed to look at the model occasionally as the image on the screen was slightly confusing.
4	1	LSA	Looking at the ship was easier. The 'look' button made it seem the arm was in a different position, and positioning the arm harder.
	6	Teacher	Not very clearly – hard to see depth on the screen – the background visual clutter also a little distracting.
Summary			
			• Some perspective difficulties • Background caused 'visual clutter'

Group No.	SP No.	Occupation	Question
			3. Did you experience any difficulties or things that didn't make sense to you?
1	*14	SaLT	No
	17	Teacher	Only difficulty was video camera – the camera made it look at a different angle to reality.
2	19	Teacher	It all made perfect sense. I had to concentrate quite hard to avoid selecting cells incorrectly – it felt quite quick.
	7	SaLT	No.
	8	LSA	No, the activity went very smoothly.
3	27	Physiotherapist	No difficulties. Slight confusion about the hand sensation and its relevant to grip although would link to 'movement'.
4	1	LSA	As above. And haptic sensation wasn't immediate on gripping item.
	6	Teacher	Glad to see other participant first – I didn't quite twig which characters I needed to move – thought I could do either until I asked for clarification.
Summary			
			• Need to synchronise haptic sensation with gripping • Some perspective issues encountered

Group No.	SP No.	Occupation	Question
			4. Other suggestions, improvement or comments:
1	*14	SaLT	You've thought of everything!
	17	Teacher	It's really great!! The screen – the speaking - the arm – the sensation all work really well together.
2	19	Teacher	Maybe sound effects – cheers, sighs, splashes.
	7	SaLT	Really lovely activity – fun & exciting!
	8	LSA	No.
3	27	Physiotherapist	Review haptic feedback sensation possibly or apply to a different area of the game. i.e. vibration when picking up the shark etc.
4	1	LSA	I'm not keen on the constant haptic sensation. Personally would prefer it on grip, attack, release only and off when just moving about.
	6	Teacher	Watching other participant, all the noise etc. seemed very distracting – but it did not seem so, nor did the haptic feedback, when I was actually doing it.
Summary			
			• Sound effects

* SP14 Did not use the system – they only observed SP17 using it

Appendix M PPs: Static image-based assessment results (Full)

Table M.1 PPs: Static image-based assessment results (Full)

		PP1		PP2	
Page No.	**Correct Answer**	**Baseline**	**Outcomes**	**Baseline**	**Outcomes**
Practice					
1	Horse (Top-Left)	Horse (Top-Left)	Horse (Top-Left)	Horse (Top-Left)	Horse (Top-Left)
2	Boat (Bottom-Right)	Boat (Bottom-Right)	Boat (Bottom-Right)	Car (Top-Left)	Boat (Bottom-Right)
3	Banana (Top-Right)	Banana (Top-Right)	Banana (Top-Right)	Banana (Top-Right)	Banana (Top-Right)
Total: Upper half (Out of 3)		**3**	**3**	**2**	**3**
Assessment					
1	Red (Top-Left)	Red (Top-Left)	Red (Top-Left)	Red (Top-Left)	Red (Top-Left)
2	Above (Bottom-Right)	In (Bottom-Left)	Above (Bottom-Right)	Far apart (Top-Left)	Far apart (Top-Left)
3	Green (Bottom-Left)	Green (Bottom-Left)	Green (Bottom-Left)	Blue (Top-Right)	Green (Bottom-Left)
4	Left (Bottom-Right)	Left (Bottom-Right)	Lower (Top-Right)	Right (Top-Left)	Lower (Top-Right)
5	In Front (Bottom-Left)	In front (Bottom-Left)	In front (Bottom-Left)	Under (Top-Left)	In front (Bottom-Left)
6	Middle (Top-Left)	Middle (Top-Left)	Middle (Top-Left)	Higher (Bottom-Left)	Higher (Bottom-Left)
7	Blue (Top-Right)	Blue (Top-Right)	Blue (Top-Right)	Green (Bottom-Left)	Green (Bottom-Left)
8	Right (Top-Left)	Lower (Top-Right)	Left (Bottom-Right)	Right (Top-Left)	Right (Top-Left)
9	Behind (Top-Right)	Behind (Top-Right)	Behind (Top-Right)	Under (Top-Left)	On (Bottom-Right)
10	Lower (Top-Right)	Lower (Top-Right)	Lower (Top-Right)	Right (Top-Left)	Higher (Bottom-Left)
11	Yellow (Bottom-Left)	Yellow (Bottom-Left)	Yellow (Bottom-Left)	Yellow (Bottom-Left)	Yellow (Bottom-Left)
12	On (Bottom-Right)	On (Bottom-Right)	On (Bottom-Right)	Under (Top-Left)	In front (Bottom-Left)
13	Higher (Bottom-Left)	Higher (Bottom-Left)	Higher (Bottom-Left)	Right (Top-Left)	Higher (Bottom-Left)
14	Under (Top-Left)	Under (Top-Left)	Under (Top-Left)	Under (Top-Left)	In front (Bottom-Left)
15	In (Bottom-Left)	In (Bottom-Left)	In (Bottom-Left)	Far apart (Top-Left)	In (Bottom-Left)
16	Far apart (Top-Left)	Far apart (Top-Left)	Far apart (Top-Left)	In (Bottom-Left)	In (Bottom-Left)
17	Near (Top-Right)	Near (Top-Right)	Near (Top-Right)	Far apart (Top-Left)	In (Bottom-Left)
Total: Lower half (out of 17)		**15**	**15**	**4**	**7**
Grand Total: Upper + Lower (out of 20)		**18**	**18**	**6**	**10**

Key: Red highlighting indicates an incorrect answer and green a correct answer

Appendix N PPs: Video-based assessment results (Full)

Table N.1 PPs: Video-based assessment results (Full)

Page No.	Question	Correct Answer		PP1						PP2					
				Baseline			Outcomes			Baseline			Outcomes		
		Answer	Position	Given answer			Given answer			Given answer			Given answer		
				No.	Concept	Position	No.	Concept	Position	No.	Concept	Position	No.	Concept	Position
1	Moving forwards	3	(Bottom-Left)	2	Moving backwards	(Top-Right)	2	Moving backwards	(Top-Right)	1	Moving up	(Top-Left)	1	Moving up	(Top-Left)
1	Moving backwards	2	(Top-Right)	3	Moving forwards	(Bottom-Left)	3	Moving forwards	(Bottom-Left)	3	Moving forwards	(Bottom-Left)	1	Moving up	(Top-Left)
1	Moving up	1	(Top-Left)	1		(Top-Left)	1		(Top-Left)	1		(Top-Left)	1		(Top-Left)
1	Moving down	4	(Bottom-Right)	4		(Bottom-Right)	4		(Bottom-Right)	4		(Bottom-Right)	4		(Bottom-Right)
2	Releasing	3	(Bottom-Left)	3		(Bottom-Left)	3		(Bottom-Left)	3		(Bottom-Left)	3		(Bottom-Left)
2	Moving left	1	(Top-Left)	1		(Top-Left)	1		(Top-Left)	3	Releasing	(Bottom-Left)	4	Moving right	(Bottom-Right)
2	Gripping	2	(Top-Right)	2		(Top-Right)	2		(Top-Right)	2		(Top-Right)	3	Releasing	(Bottom-Left)
2	Moving right	4	(Bottom-Right)	4		(Bottom-Right)	4		(Bottom-Right)	1	Moving left	(Top-Left)	1	Moving left	(Top-Left)
Totals (out of 8)				6			6			4			3		

Key: Red highlighting indicates an incorrect answer and green a correct answer

Appendix O PPs: Physical touch and haptic sensations results (Full)

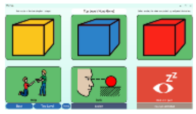
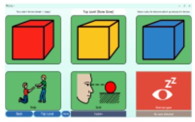
Table O.1 PPs: Physical touch and haptic sensations results (Full)

Trial No.	Correct Answer	P1				P2			
		Physical		Haptic		Physical		Haptic	
		Baseline	Outcome	Baseline	Outcome	Baseline	Outcome	Baseline	Outcome
		05/05/2017	04/07/2017	09/05/2017	05/07/2017	10/05/2017	04/07/2017	11/05/2017	05/07/2017
1	Left	Left	Left	Left	Left	Both	Right	Left	Left
2	Right	Right	Right	Right	Right	Both	Right	Right	Right
3	Right	Right	Right	Right	Right	Both	Right	Right	Right
4	Left	Left	Left	Left	Left	None	Left	Left	Left
5	None	None	None	None	None	None	Both	None	None
6	Right	Right	Right	Right	Right	Both	Right	Right	Right
7	Both	Both	Both	Both	Both	None	Right	Both	Both
8	None	None	None	None	None	Left	Right	None	None
9	Left	Left	Left	Left	Left	None	Left	Left	Left
10	Both	Both	Both	Both	Both	None	Both	Right	Both
11	Left	Left	Left	Left	Left	Both	Left	Left	Left
12	None	None	None	None	None	None	None	None	None
13	Both	Both	Both	Both	Both	Both	Right	Right	Both
14	Right	Right	Right	Right	Right	Both	Right	Right	Right
15	None	None	None	None	None	None	None	Both	None
16	Both	Both	Both	Both	Left	Both	Both	Right	Both
17	None	None	None	None	None	None	None	None	None
18	Left	Left	Left	Left	Left	Both	Left	Left	Left
19	Both	Both	Both	Both	Both	Both	Right	Right	Both
20	Right	Right	Right	Right	Right	None	Right	Both	Right
Totals		20/20	20/20	20/20	19/20	7/20	14/20	14/20	20/20

Key: Red highlighting indicates an incorrect answer and green a correct answer

Appendix P PP1: Intervention - 'Cubes' results (Full)

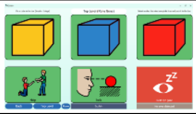
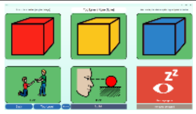
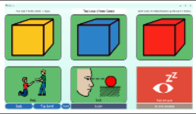
Table P.1 PP1: 'Cubes' 2 results (Full)

Task No.	**Description of task**	**Answered**	**Comments**
Using original interface (cell positions map directly to those of the 'live'/real scene)			
1	All cubes	Correct	PP1: R, B, Y (Right to left)
2	Blue cube (replaced)	Correct	
3	Red cube (replaced)	Correct	
4	Yellow cube (replaced)	Correct	
5	Yellow cube (not replaced)	Correct	
6	Blue cube (not replaced)	Correct	
7	Yellow cube (not there!)	Incorrect	Tried Y
8	Red cube (replaced)	Correct	
9	Middle cube	Correct	
10	Left cube	Incorrect	Chose right (R)
11	Right cube	Incorrect	Chose left (Y)
Using 'mixed'/rearranged interface (cell positions do not map directly to those of the 'live'/real scene)			
12	Blue cube	Correct	
13	Red cube	Correct	
14	Yellow cube	Correct	
Total correct		11/14	

Key: Red highlighting indicates an incorrect answer and green a correct answer

PP1: Full results of 'Cubes 3'

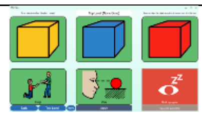
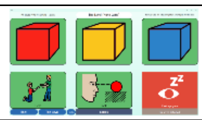
Table P.2 PP1: 'Cubes' 3 results (Full)

Task No.	Description of task	Answered	Comments
Using original interface (cell positions map directly to those of the 'live'/real scene)			
15	Put cube in box (Pointed to real red cube) (replaced)	Correct	
16	Put cube in box (Pointed to real yellow cube) (replaced)	Correct	
17	Put cube in box (Pointed to real blue cube) (replaced)	Correct	
Using 'mixed'/rearranged interface (cell positions do not map directly to those of the 'live'/real scene)			
18	Put cube in box (Pointed to real blue cube) (replaced)	Correct	
19	Put cube in box (Pointed to real red cube) (replaced)	Correct	
20	Put cube in box (Pointed to real yellow cube) (replaced)	Correct	
Using original interface (cell positions map directly to those of the 'live'/real scene)			
21	Put all cubes in box starting from left	Incorrect	Started from right
22	Put all cubes in box starting from right	Correct	R, B, Y (Right to left)
23	Put blue & red cubes in box	Correct	B, R (& Y)
24	Put yellow & blue cubes in box	Incorrect	Y (forgot B until prompted)
25	Put red and yellow cubes in box	Incorrect	R (forgot Y until prompted)
29	Put the middle & left cubes in box	Incorrect	Middle (B) (forgot Left/Y until prompted)
30	Put left & right cubes in box	Incorrect	Left (Y) (forgot Right/R until prompted)
Total correct		8/13	

Key: Red highlighting indicates an incorrect answer and green a correct answer

Appendix Q PP2: Intervention - ‘Cubes’ results (Full)

Table Q.1 PP2: ‘Cubes’ 2 results (Full)

Task No.	**Description of task**	**Answered**	**Comments**
Using original interface (cell positions map directly to those of the ‘live’/real scene)			
1	All cubes	Incorrect	Y, B, B, R (Left to right)
2	Blue cube (replaced)	Correct	
3	Red cube (replaced)	Incorrect	Y
4	Yellow cube (replaced)	Incorrect	R
5	Yellow cube (not replaced)	Correct	
6	Blue cube (not replaced)	Correct	
7	Yellow cube (not there!)	Incorrect	R
8	Red cube (replaced)	Correct	
9	Middle cube	Correct	
10	Left cube	Incorrect	Chose middle (B)
11	Right cube	Correct	
Using 'mixed'/rearranged interface (cell positions do not map directly to those of the ‘live’/real scene)			
12	Blue cube	Correct	
13	Red cube	Incorrect	Y
14	Yellow cube	Incorrect	R
Total correct		7/14	

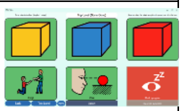
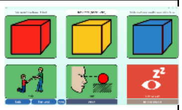
Key: Red highlighting indicates an incorrect answer and green a correct answer

Colour question answer scores:

- Blue 3/3
- Red 1/3
- Yellow 1/4

PP2: Full results of 'Cubes 3'

Table Q.2 PP2: 'Cubes' 3 results (Full)

Task No.	Description of task	Answered	Comments
Using original interface (cell positions map directly to those of the 'live' / real scene)			
15	Put cube in box (Pointed to real red cube) (replaced)	Correct	
16	Put cube in box (Pointed to real yellow cube) (replaced)	Correct	
17	Put cube in box (Pointed to real blue cube) (replaced)	Correct	
Using 'mixed'/rearranged interface (cell positions do not map directly to those of the 'live'/real scene)			
18	Put cube in box (Pointed to real blue cube) (replaced)	Correct	
19	Put cube in box (Pointed to real red cube) (replaced)	Correct	
20	Put cube in box (Pointed to real yellow cube) (replaced)	Correct	
Total correct		6/6	

Key: Red highlighting indicates an incorrect answer and green a correct answer

Appendix R Intervention: Final LSA questionnaire

Final Questionnaire

Your Name: ____________________ Date: ____________________

Just to remind you, the activities that you observed the participants performing using the robotic arm were:

a. Picking up cubes and putting them in a box
b. 'Feeding' the giraffe
c. Knocking down 'towers' of blocks
d. Story-based play involving a pirate ship

1. Which of these activities do you consider the participants found:
   a. The most enjoyable (please circle one or more)?

P1	a	b	c	d	None
P2	a	b	c	d	None

   b. The most difficult (please circle one or more)?

P1	a	b	c	d	None
P2	a	b	c	d	None

2. Did you think that the participant(s) would be able to control a robotic arm? Please explain your answer.

3. Has seeing the participant(s) use the robotic arm changed the way that you think about them (if so please explain)?

4. Were there any moments that particularly stood out for you?

5. Do you consider that the participant(s) has/have learned new skills? If so what?

6. Have you discovered things about the participant(s) that you didn't know? If so, what?

7. Do you think that the haptic feedback device was useful (please explain your answer)?

8. Could you please suggest any other activities that the participant(s) could perform using the robotic arm?

9. Any other comments or suggestions?

Thank you very much for taking part in this research.

Mark

Figure R.1 PPs - Intervention: Final LSA questionnaire (Form)

Intervention: Final LSA questionnaire (Answers)

Table R.1 PPs - Intervention: Final LSA questionnaire (collated answers)

LSA No.	Question					
	a. Picking up cubes and putting them in a box b. 'Feeding' the giraffe c. Knocking down 'towers' of blocks d. Story-based play involving a pirate ship **1. Which of these activities do you consider the participants found:**					
	a. The most enjoyable (please circle one or more)?					
1	PP1	a	b	ⓒ	ⓓ	None
2	PP2	a	b	ⓒ	ⓓ	None
	b. The most difficult (please circle one or more)?					
1	PP1	a	b	c	ⓓ	None
2	PP2	a	ⓑ	c	ⓓ	None
	Summary Activities c and d were rated as the most enjoyable for both PPs Activity d was also rated as 'most difficult' for both PPs					

LSA No.	Question
	2. Did you think that the participant(s) would be able to control a robotic arm? Please explain your answer.
1	I thought PP1 would be able to do it. I was surprised how well he did it.
2	I actually hadn't really thought about whether the participant would be able to, I was just excited about seeing what was involved.
	Summary LSA 1 was surprised at how well PP1 was able to control the robotic arm

LSA No.	Question
	3. Has seeing the participant(s) use the robotic arm changed the way that you think about them (if so please explain)?
1	Given me some ideas for future uses and things like positional words (left/right and forwards/backwards) to do more work on in class.
2	I was really pleased to see how much participant 2 got out of using the robotic arm. His focus was really good and he really seemed to enjoy it.
	Summary LSA 1 had ideas for what to work on in class with PP1 LSA was pleased to see PP2 enjoying using the system

LSA No.	Question
	4. Were there any moments that particularly stood out for you?
1	To see both participants work out moves was amazing. They both did better than I had expected.
2	Really, participant 2's ability to transfer his problem solving skills to another situation. Also his determination and focus, particularly for long periods of time, and even when not being in a great mood at the start of a session, he quickly got on with the job in hand and thoroughly enjoyed it.
	Summary LSA 1 reported that both PPs did better than expected LSA 2 was impressed by PP2's problem solving skills, determination and sustained focus. Change in mood.

LSA No.	Question
	5. Do you consider that the participant(s) has/have learned new skills? If so what?
1	Needed patience as some activities took a while to set up. They both obviously enjoyed the activity as moods and determination showed when they went for sessions.
2	Participant 2 has become more aware of his left and right and also how it feels to hold and move objects.

	Also he has learnt more about spatial awareness.
	Summary LSA 1 considered that PP1 had developed patience LSA believed that PP2 had become more aware of his left and right and how it feels to 'hold' and move objects and also spatial awareness

LSA No.	**Question**
	6. Have you discovered things about the participant(s) that you didn't know? If so, what?
1	Need more support with L/R. Already know, but enforced willingness to please/work even when uncomfortable.
2	How participant 2 can be motivated with the right activity, also how independent he can be.
	Summary LSA 1 stated that she considered that PP1 needed more help with the concepts of left and right LSA 2 discovered that PP2 can be motivated and independent when appropriate opportunities are presented.

LSA No.	**Question**
	7. Do you think that the haptic feedback device was useful (please explain your answer)?
1	Worked well as a 'new' experience as participants have only ever had hand over hand, or helped movement to experience such feeling. Both showed signs of surprise and enjoyment.
2	Yes, because the participants got the sensation of how it feels to move an object. Also the sensation helps to make the experience more fulfilling and interesting.
	Summary LSA 1 believed that the haptic was valuable and that the PP's enjoyed the sensation LSA 2 considered the haptic device to be important to the overall experience.

LSA No.	**Question**
	8. Could you please suggest any other activities that the participant(s) could perform using the robotic arm?
1	Could aid story making activities, and sequencing work. Both things Participant A (PP1) struggles with. Excellent for reinforcing positional words.
2	Pouring dry substances e.g. rice, sand, pasta
	Summary LSA 1 suggested using for story making, sequencing and reinforcing positional words. LSA 2 suggested pouring dry substances e.g. rice, sand, pasta

LSA No.	**Question**
	9. Any other comments or suggestions?
1	Would like to use again for same activities and to make and act out new stories. Possibly using characters/objects made in other lessons.
2	I think Participant 2 would benefit from further activities like this. I could see that his concentration would really improve from these experiences. I really am pleased to have seen how much he got out of this and have really enjoyed being involved. Thank you Mark.
	Summary LSA 1 wished to use the same and new activities with the PP's LSA 2 also wanted to use the system for other activities to develop PP2's concentration.

Appendix S PPs - Intervention: LSA Session notes

S.1 LSA 1: Session notes

Directions

6/6/17 Tuesday 13:15 PP1 with LSA 1 – Directions 2 - Towers 1
Gets frustrated quickly when waiting, making next task harder until he settles again.
Worked out quickly right and left movements when wrong select first.
Up and down took extra goes to get used to, same as forwards and backwards.
Remembered after a technical issue break which way to move. Often forgets after a short break.

7/6/17 Wednesday 13:15 PP2 with LSA 1 – Directions 2 - Towers 1
Came into school in a grumpy mood but mood changed when he realised it was research day and was very happy to come and work.
Worked out quickly after initial mistake left or right.
Enjoyed the fact it was all going wrong!
Took a few goes to understand forwards/backwards when needing to move backwards.
Very keen to knock down the last one after the effort to build it.

8/6/17 Thursday 13:15 PP1 with LSA 1 – Directions 2 - Towers 2
Giggly but getting frustrated with eye gaze
Forgot what he was doing in the short gap while eye gaze off.
Very surprised with working out so quickly.
PP1 was least frustrated out of the 3 of us about the eye gaze problems.
Excellent working out of the puzzle ☺
Getting quicker every time, amazing problem solving.
Wow! Just wow! Smug face
Completely amazed – I was unsure if PP1 would be able to work these out.
Good planning but gives in easily and asks for help before trying something he is unsure of.

12/6/17 Monday 13:15 PP1 with LSA 1 – Directions 2 - Towers 2 (Continued)
Gives up very easily on first go, a lot sooner than I expected him to.
Suggestion for improvement: Would an 'easy' warm up exercise help to concentrate and get back into it.

15/06/17 Thursday PP1 with LSA 1 – Directions 2 - Towers 2 (Continued)
Much better today with left/right
Suggestion for improvement: I think the arrows backwards/down and forwards/up were confusing for PP1 as they both had arrows.
When 'on a roll' moving arm is easy.

Scenarios

21/06/17 Wednesday PP1 with LSA 1 – Scenarios
Suggestion for improvement: Possibly have a winner card to remind who is the winner. Printed picture?
PP1 really struggling with the heat today – so did really well.

23/06/17 Friday PP1 with LSA 1 – Scenarios
PP1 much cooler (weather) and able to concentrate better today.
Seems worried about doing if wrong; likes to ask for help very quickly.
Got quite frustrated when he couldn't work out what to do next. Didn't want to try something different.

Overall Summary

PP1:

- Gets frustrated at times e.g. when waiting, when he can't work something out
- Often forgets
- Getting quicker at solving problems
- Excellent problem-solving

- Felt that he can give up easily
- Issues with left/right
- Heat affected him
- Appears worried about doing something wrong. Asks for help quickly

PP2:

- Mood change when he realised it was research day
- Enjoys things going wrong!
- Determined to knock down

S.2 LSA 2: Session notes

Directions

09/06/17 Friday 13:15 PP2 with LSA 2 – Directions 2 - Towers 2
Always very keen to start each task and needs no prompting.
Very focussed when doing task.
Works out problems quickly.
Realises how to correct any wrong moves quickly.
Enjoys knocking tower down.
Mark very attentive to PP2's needs whilst he waits for new task.
PP2 got the hang of using two directional movements (forwards/backwards, left/right) really easily.
Didn't remember which way was left and which way was right from previous task – I thought he may have remembered.
PP2 found left/right, up/down easy to do.
I feel very happy seeing PP2 get so much enjoyment from task and being so focussed.
PP2 found up/down easy to use (PP2 hadn't needed up/down so worked it out himself).

13/06/17 Tuesday 13:15 PP2 with LSA 2 – Directions 2 - Towers 2 (Continued)
PP2 likes the screen on to see the tower being built.
PP2 started straight away with the correct movement (left)
(left/right up/down)
PP2 moved the arm in exactly the right way. Down twice, left twice
Perfect!!
(left/right forwards/backwards)
PP2 moved the arm again in the right way with fewest moves.
Perfect.
(F/B U/D)
PP2 chose to just use forwards, which surprised me.
(F/B L/R)
PP2 moved forwards instead of backwards to start with. PP2 kept going left and then worked out he needed to go backwards
(L/R F/B)
PP2 started going left (wrong way) and then realised.
Help needed/requested: PP2 asked for help. He didn't try out forwards backwards which surprised me.
Help needed/requested: Mark suggested backwards.
PP2 has really enjoyed all the tasks today and particularly enjoyed things going wrong. Really nice to see PP2 happy.
(L/R U/D)
PP2 worked out that going up would get the block that was overhanging – really good.

20/06/17 PP2 with LSA 2 – Directions 2 - Towers 2 (Continued)
L/R U/D
PP2 took a while with this but worked out how to get to the blue block at the top. Very well worked out.
F/B U/D
PP2 took a lot of time with this, working it out carefully. Did it really well though.
Using stick F/B U/D
PP2 moved up to correct place and then moved it back down again which took it to the wrong place.
Help needed/requested: PP2 needed help. He listened to Mark's instructions and followed them well.
U/D F/B L/R
Practice moves. L & R mixed up. Picked left straight away for direction towards tower. Use up though, which took him away from tower. PP2 didn't try down. He used left & forwards.
PP2 asked for help, PP2 got confused even after help.
Help needed/requested: Needed lots of help after this to complete the task. PP2 showed great determination to complete the task.
PP2 completed this task very quickly.
Final task –

PP2 was determined to knock more of the second tower down, kept trying and got more cubes until he couldn't reach any more.
Final tower easily got.

Scenarios

22/06/16 PP2 with LSA 2 - Scenarios
Pirate ship
PP2 coped well with technical problems.
PP2 enjoyed this activity.
Tried pushing boundaries but the robotic arm wouldn't let PP2 do everything he wanted.
Help needed/requested: PP2 needed help, asked for hint but PP2 picked the wrong cell.
PP2 worked out what he needed to do in the end.
Well done!
PP2 chose to do the activity for a third time. Chose crab as winner this time.
Still pushing boundaries and enjoying it.

Overall Summary

PP1:
N/A

PP2:
Always keen to start and very focussed.
Good and quick problem solving skills.
Good at correcting mistakes
Found it easy
Liked being able to watch the towers being built onscreen
Good at following instructions
Determined

Appendix T PPs - Intervention: NASA-TLX forms completed

Table T.1 PPs - Intervention: NASA-TLX forms completed

		PP1				PP2			
		Task No.	**LSA**	**No. of forms**		**Task No.**	**LSA**	**No. of forms**	
Cubes	1	N/A	1	1		N/A	1	1	
	2	All	2	1		All	2	1	
	3	All	1	1		All	1	1	
Total				3				3	
Directions	Towers 1	1	1	1	Paperwork error (only 5 forms completed – should have been 6) Redone from video 4 was set up incorrectly and was redone in Towers 2	1	1	1	Paperwork error (only 5 forms completed – should have been 6) Redone from video
		2	1	1		2	1	1	
		3	1	1		3	1	1	
		4	~~1~~	~~1~~		4	1	1	
		5	1	1		5	1	1	
		6	1	1		6	1	1	
	Towers 2	4	1	1	Paperwork error (only 6 forms completed – should have been 7) Redone from video				
		7	1	1		7	2	1	Forgot to do in session – done using video
		8	1	1		8	2	1	
		9	1	1		9	2	1	
		11	1	1		11	2	1	
		13	1	1		13	2	1	
		15	1	1		15	2	1	
		10	1	1		10	2	1	
		16	1	1		16	2	1	
		14	1	1		14	2	1	
		17	1	1		17	2	1	
		18	1	1		18	2	1	
		12	1	1		12	2	1	
		19	1	1		19	2	1	
		20	1	1		20	2	1	
		24	1	1		24	2	1	
Total				21				21	
Scenarios	Scenarios 1		1	1			2	1	
	Scenarios 2		1	1			N/A	N/A	
			1	1			N/A	N/A	
			1	1			N/A	N/A	
Total				4				1	

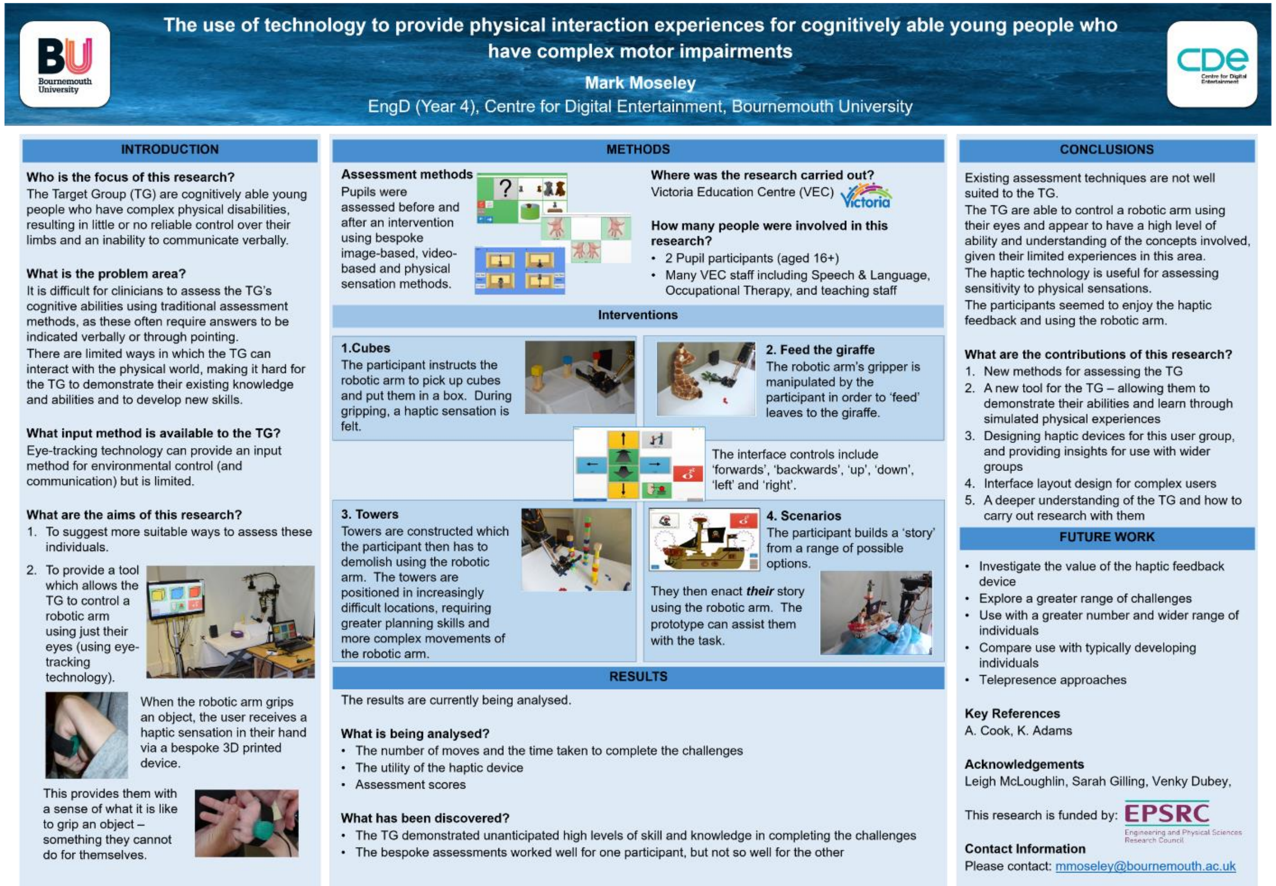
Key: Areas highlighted in red indicate an error with the NASA-TLX form. Yellow indicates when a configuration error occurred.

Appendix U Static image-based assessment - sample log file

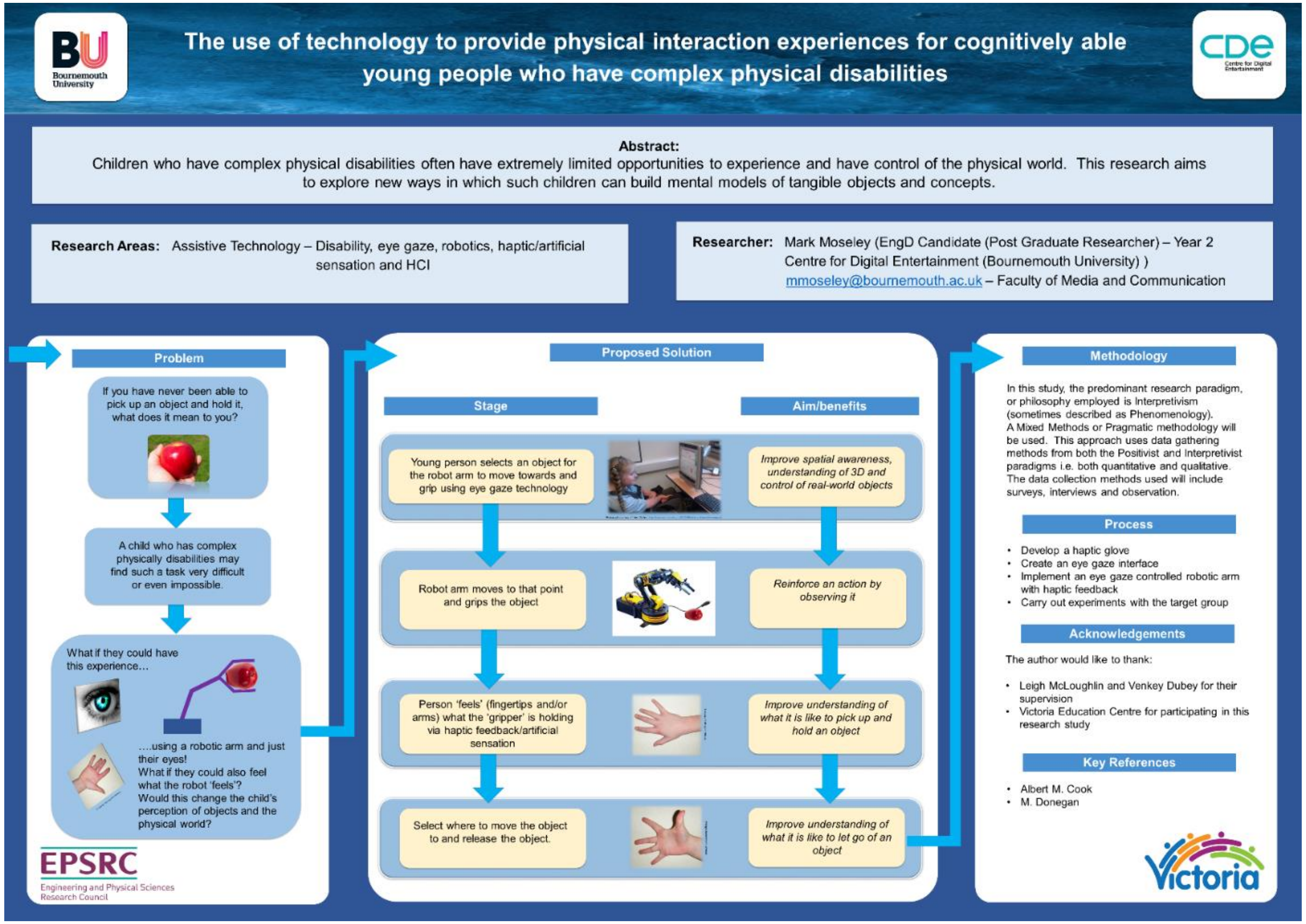
Date	Time	Page	Cell/Correct Answer	Given Answer	Correct/Incorrect
27/06/2017	14:16:47	Right	Which one is right?		
27/06/2017	14:16:54	Right	Which one is right?		
27/06/2017	14:17:01	Right	Right (Top-Left)	Left (Bottom-Right)	Incorrect
27/06/2017	14:17:07	Behind	Which one is behind the table?		
27/06/2017	14:17:20	Behind	Which one is behind the table?		
27/06/2017	14:17:27	Behind	Behind (Top-Right)	Behind (Top-Right)	Correct
27/06/2017	14:18:09	Lower	Which one is lower?		
27/06/2017	14:18:18	Lower	Which one is lower?		
27/06/2017	14:18:24	Lower	Lower (Top-Right)	Lower (Top-Right)	Correct

Appendix V Academic posters

CVMP (the 14th European Conference on Visual Media Production)

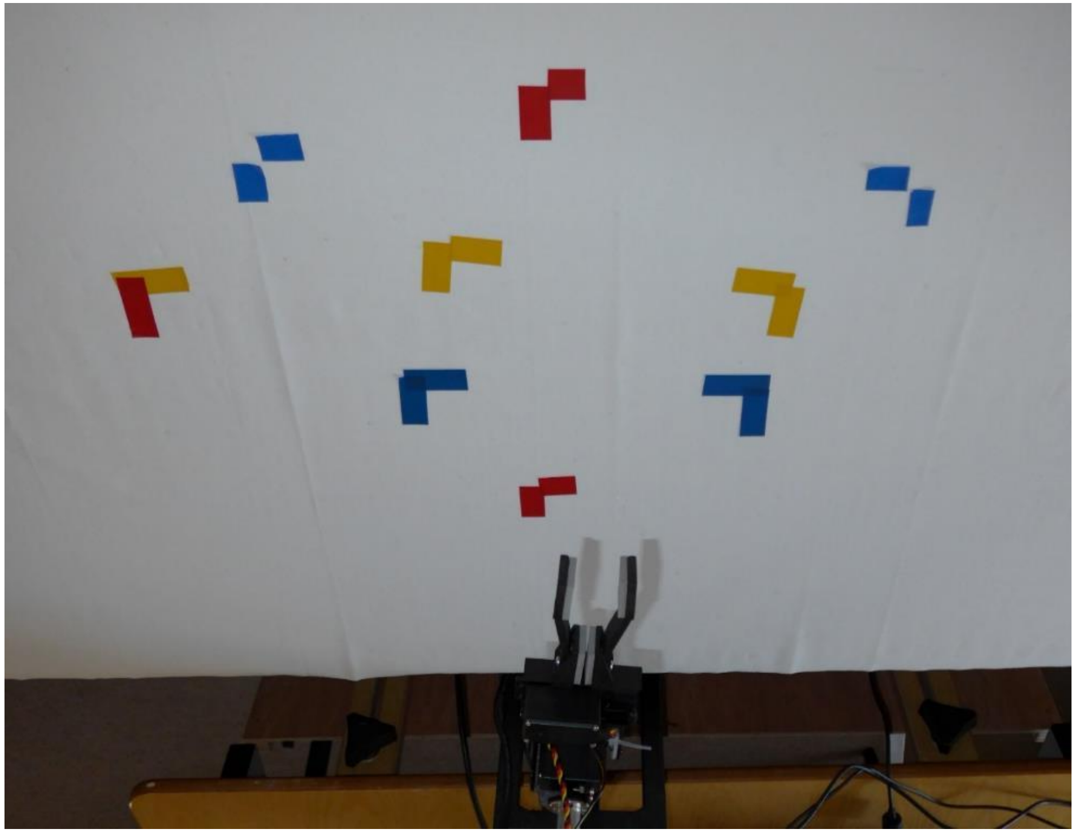


The 30th International BCS Human Computer Interaction Conference (HCI 2016):



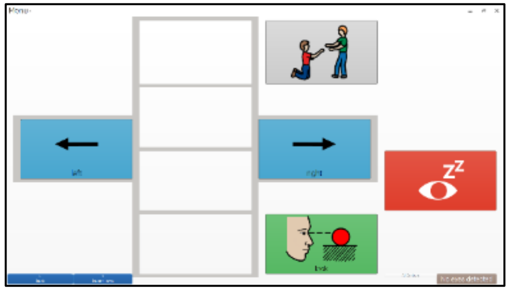
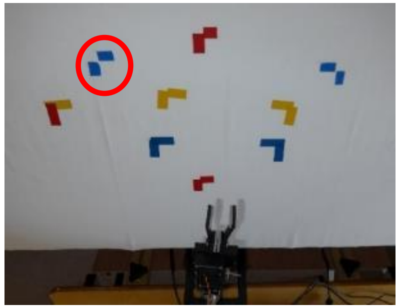
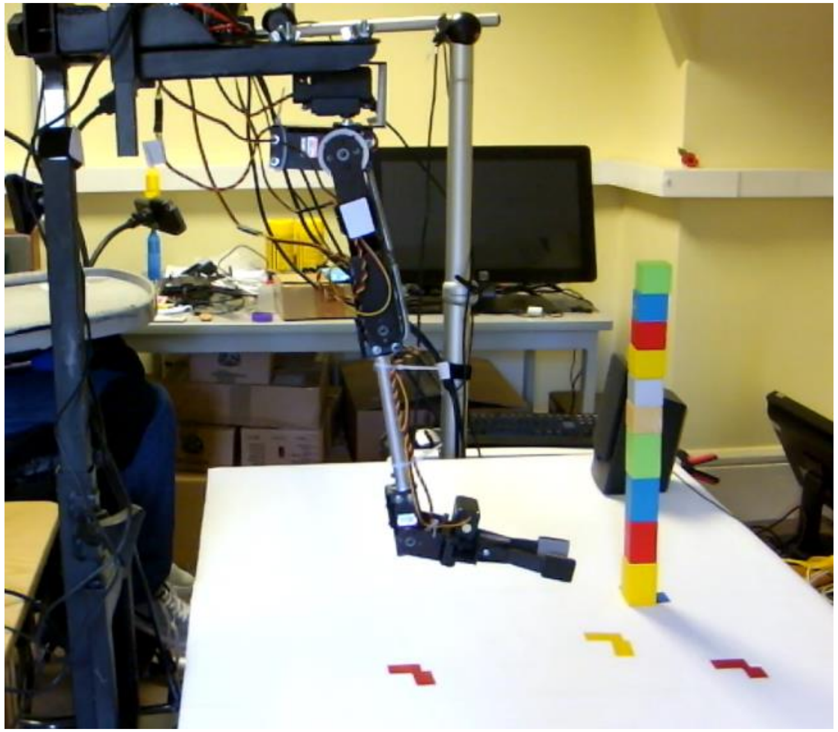
Appendix W Intervention Tasks: 'Directions' – 'Towers' (Pictures)

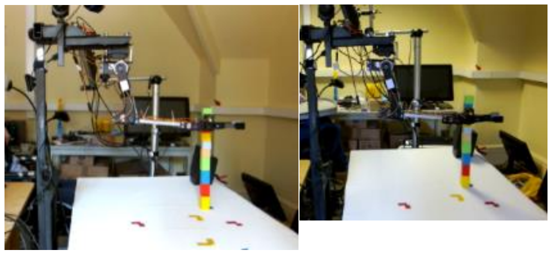
Table markings (for positioning towers)



1. Left

Challenge Number	Order Performed	Direction controls provided	Structure Type	Location	Arm start Position (software)	X, y Coords	Position of tower (marker colour)
1	1	Left/Right	Tower	Left	Left & Right	8, 7, 90	Blue- Left- Forwards

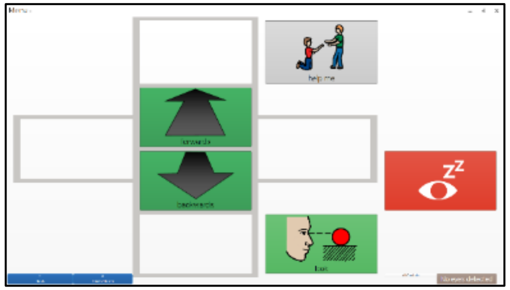
Interface	Position of tower	Alternative view
		

Starting position	
Right side view	Above
	

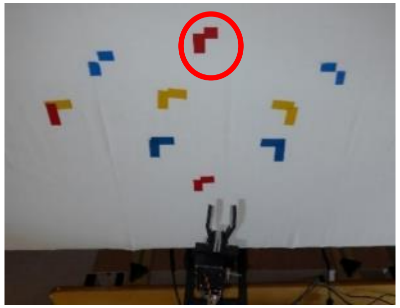
2. Forwards

Challenge Number	Order Performed	Direction controls provided	Structure Type	Location	Arm start Position (software)	X, y Coords	Position of tower (marker colour)
2	2	Forwards/Backwards	Tower	Forwards	Forwards	2, 7, 90	Red- Forwards

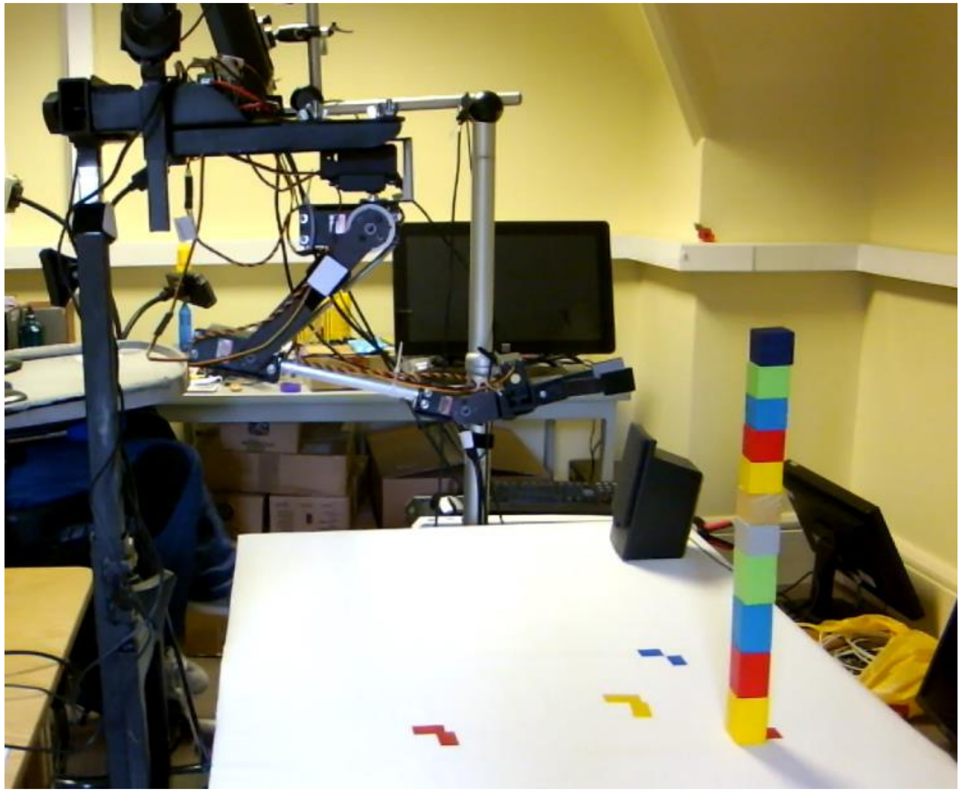
Interface



Position of tower

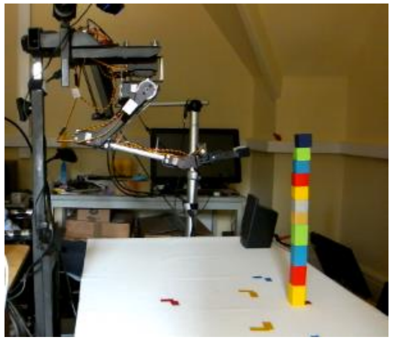


Alternative view



Starting position

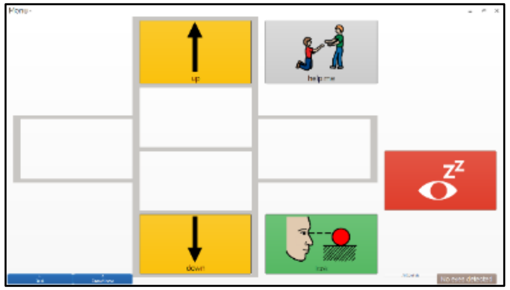
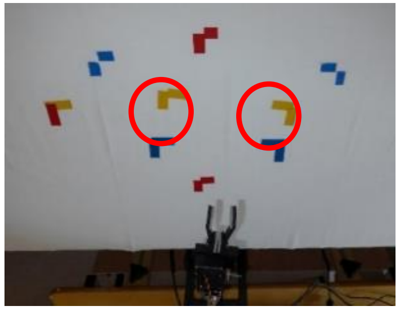
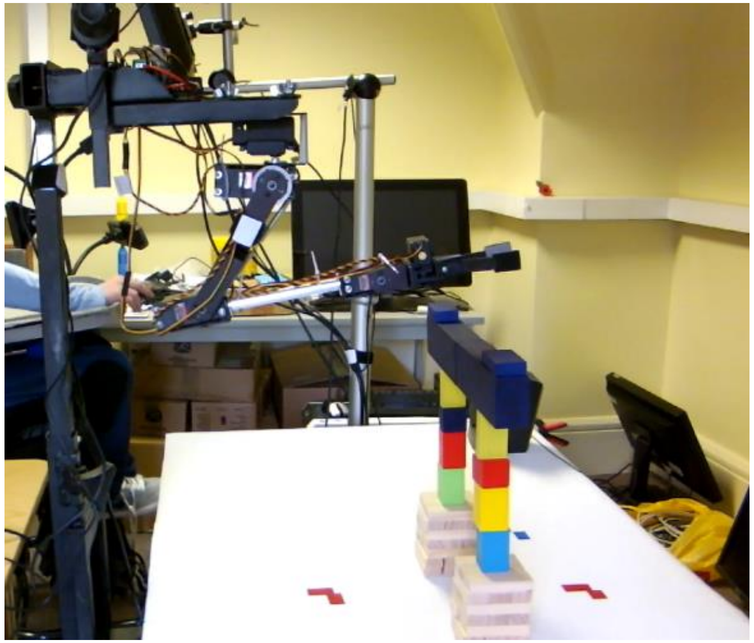
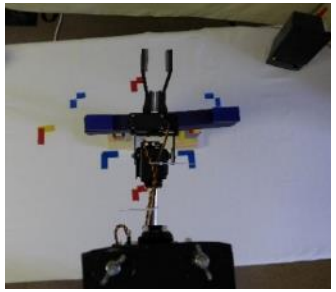
Right side view



Above

3. Down

Challenge Number	Order Performed	Direction controls provided	Structure Type	Location	Arm start Position (software)	X, y Coords	Position of tower (marker colour)
3	3	Up/Down	Arch	Down	Down	4, 5, 90	Middle (Near yellows)

<table>
<tr><th>Interface</th><th>Position of tower</th><th>Alternative view</th></tr>
<tr><td></td><td></td><td rowspan="4"></td></tr>
<tr><th colspan="2">Starting position</th></tr>
<tr><th>Right side view</th><th>Above</th></tr>
<tr><td></td><td></td></tr>
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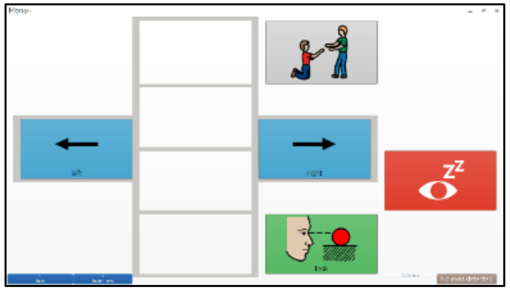
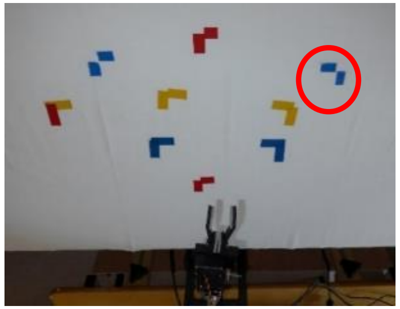
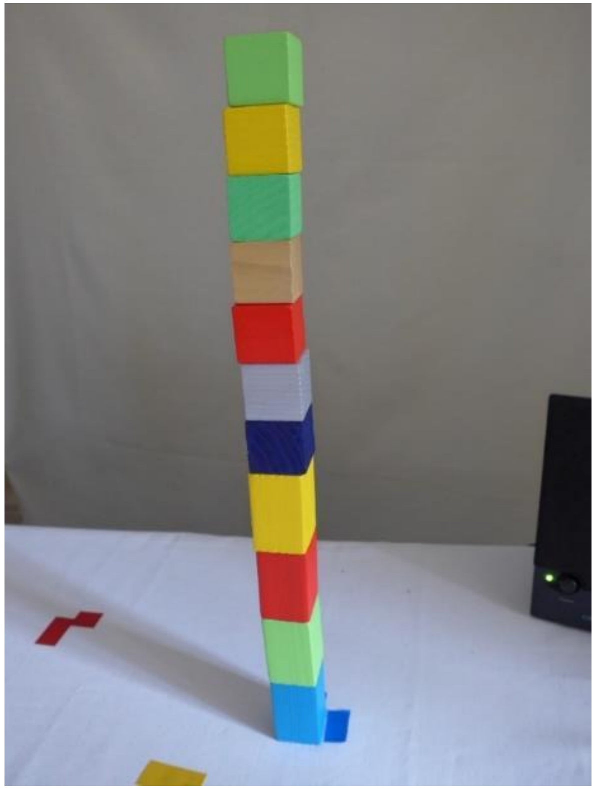
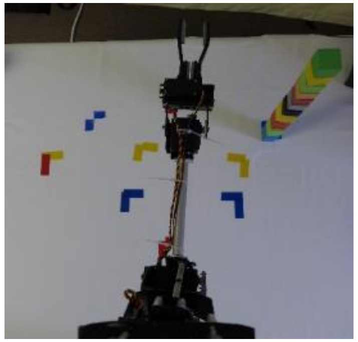
4. Right

Challenge Number	Order Performed	Direction controls provided	Structure Type	Location	Arm start Position (software)	X, y Coords	Position of tower (marker colour)
4	4	Left/Right	Tower	Right	Left & Right	8, 7, 90	Blue- Right- Forwards

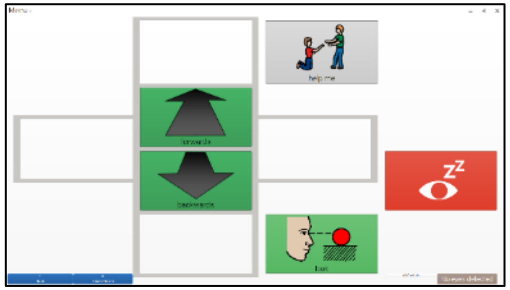
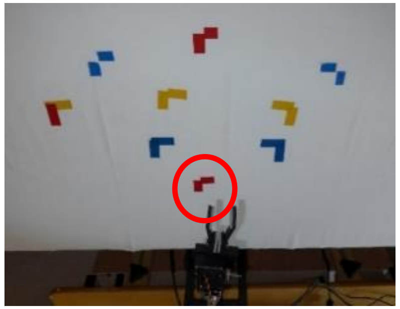
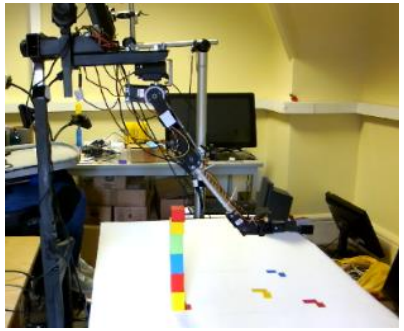
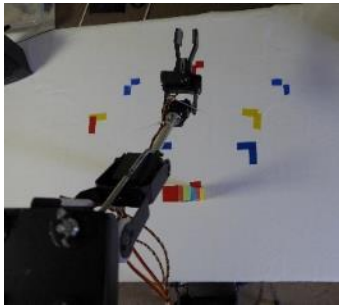
Interface	Position of tower	Alternative view
		

Starting position

Right side view	Above
	

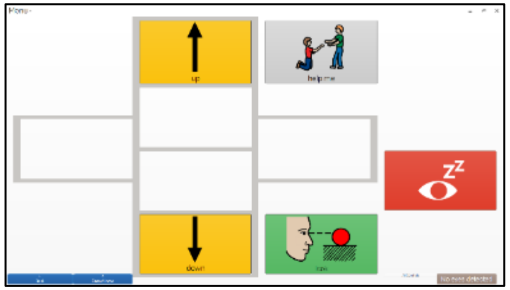
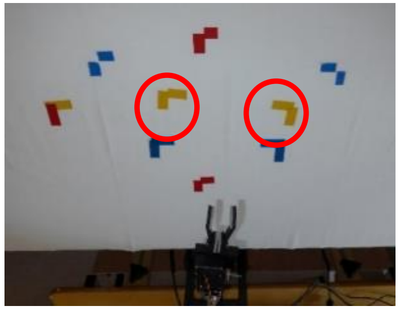
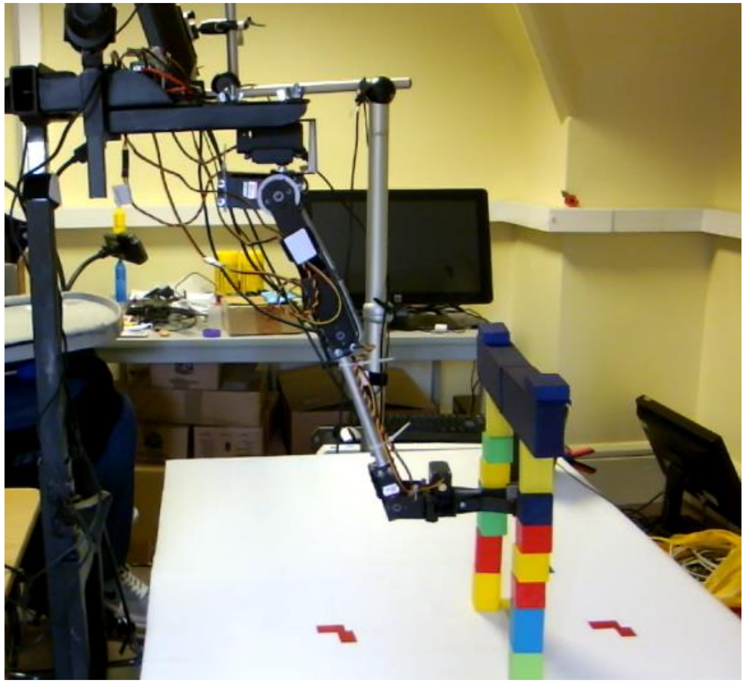
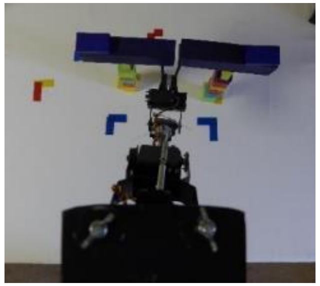
5. Back

Challenge Number	Order Performed	Direction controls provided	Structure Type	Location	Arm start Position (software)	X, y Coords	Position of tower (marker colour)
5	5	Forwards/Backwards	Tower	Backwards	Backwards	7, 11, 90	Red- Back

Interface	Position of tower	Alternative view
		
Starting position		
Right side view	Above	
		

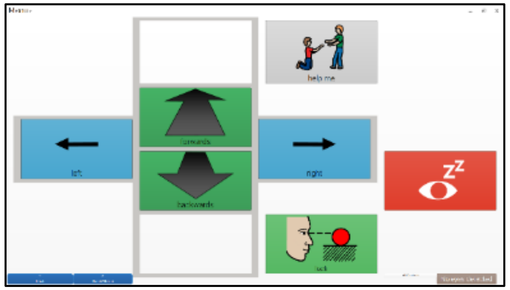
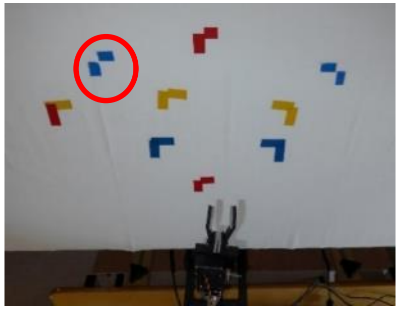
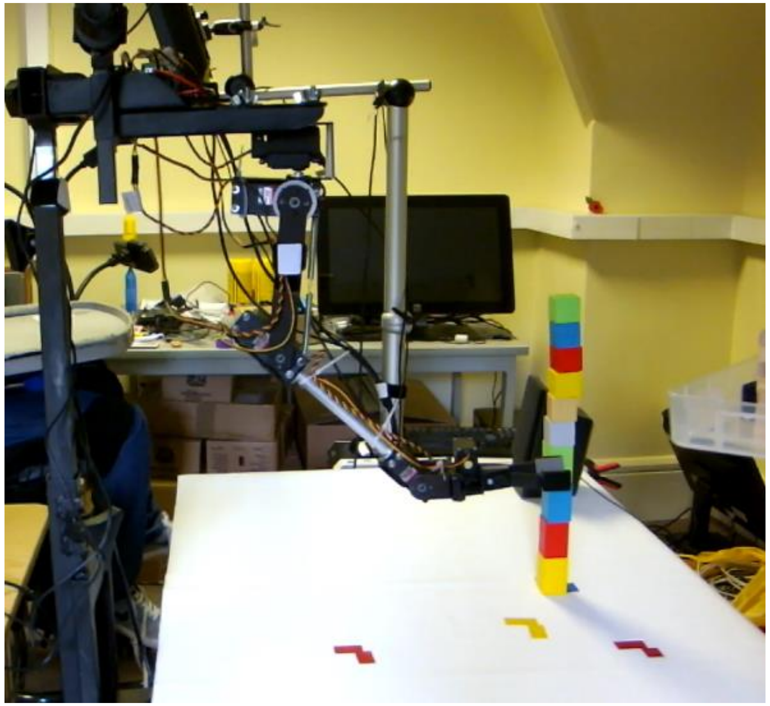
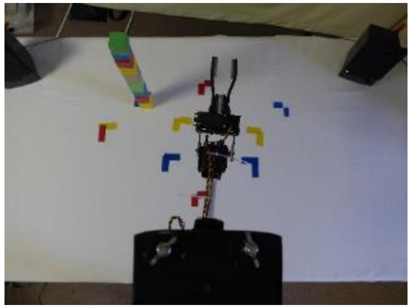
6. Up

Challenge Number	Order Performed	Direction controls provided	Structure Type	Location	Arm start Position (software)	X, y Coords	Position of tower (marker colour)
6	6	Up/Down	Arch	Up	Up	4, 13, 90	Middle (Near yellows)

Interface	Position of tower	Alternative view
		
Starting position		
Right side view	Above	
		

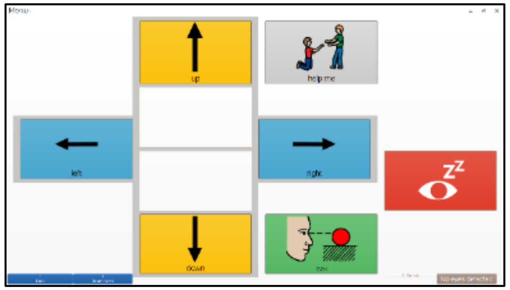
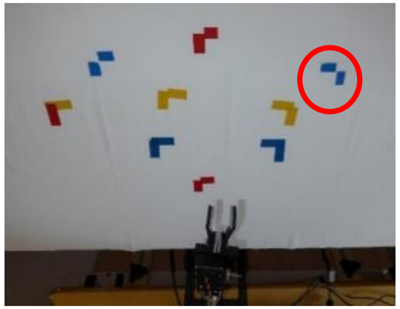
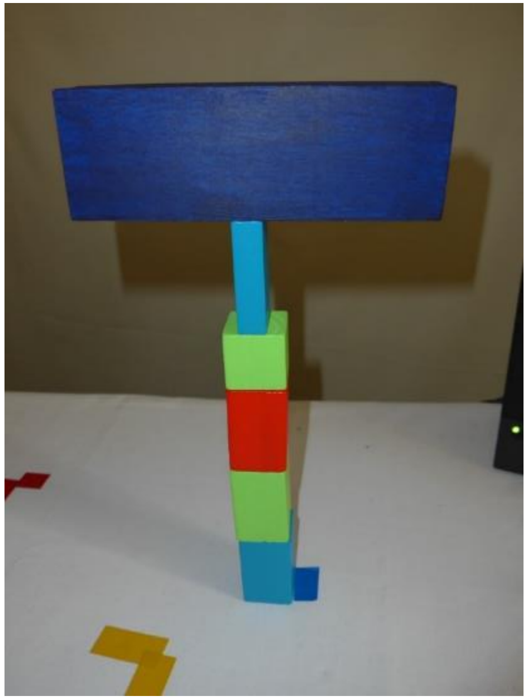
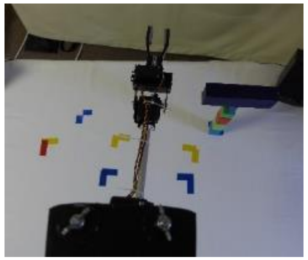
7. Left and Forwards

Challenge Number	**Order Performed**	**Direction controls provided**	**Structure Type**	**Location**	**Arm start Position (software)**	**X, y Coords**	**Position of tower (marker colour)**
7	7	Left/Right Forwards/Backwards	Tower	Left Forwards	Left-Forwards	4, 7, 90	Blue Left Forward

Interface	Position of tower	Alternative view
		
Starting position		
Right side view	Above	
		

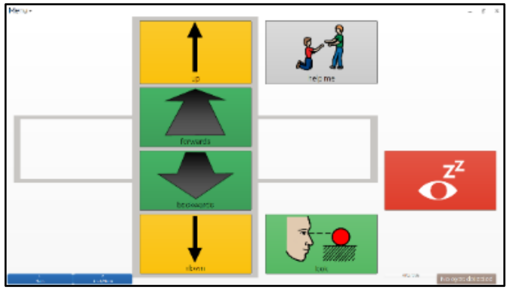
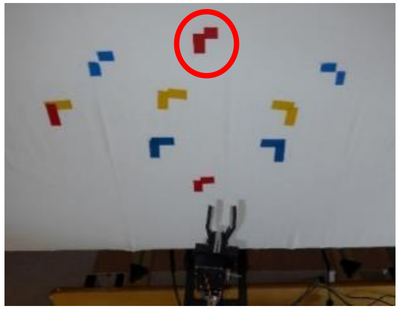
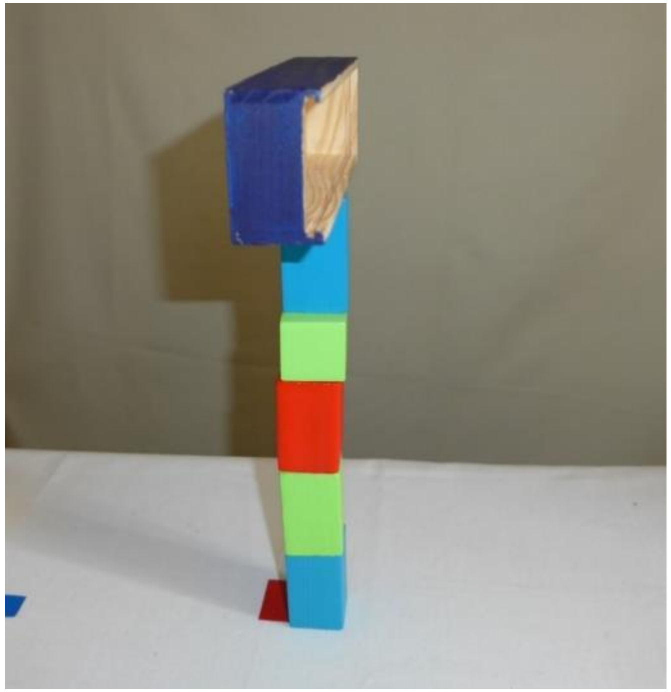
8. Right and Down

Challenge Number	Order Performed	Direction controls provided	Structure Type	Location	Arm start Position (software)	X, y Coords	Position of tower (marker colour)
8	8	Left/Right Up/Down	Tower	Right Down	Right-Down	8, 7, 90	Blue Right Forward

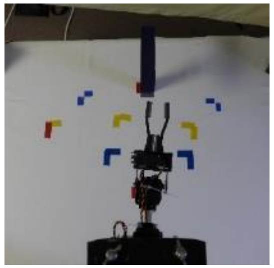
Interface	Position of tower	Alternative view
		
Starting position		
Right side view	Above	
		

9. Forwards and Down

Challenge Number	Order Performed	Direction controls provided	Structure Type	Location	Arm start Position (software)	X, y Coords	Position of tower (marker colour)
9	9	Forwards/Backwards Up/Down	'T'	Forwards Down	Forwards-Down	2, 7, 90	Red- Forward

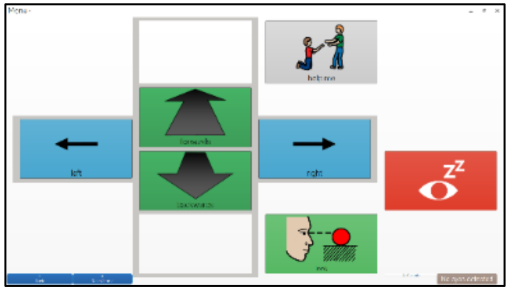
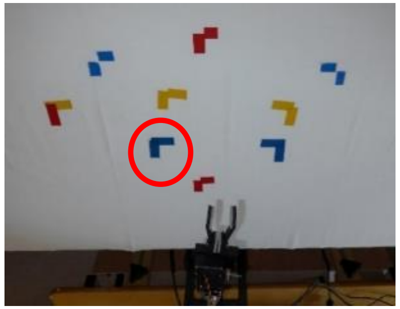
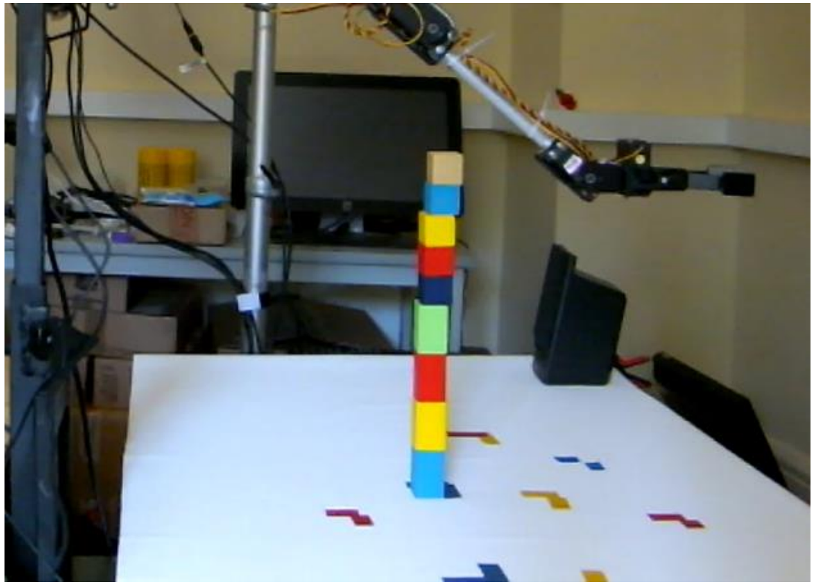
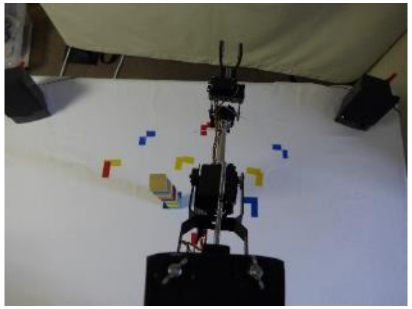
Interface	Position of tower	Alternative view
		

Starting position

Right side view	Above
	

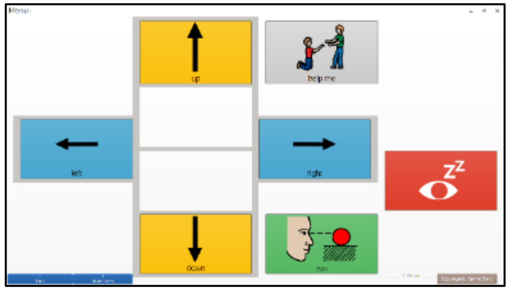
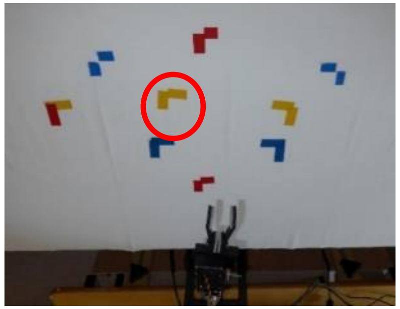
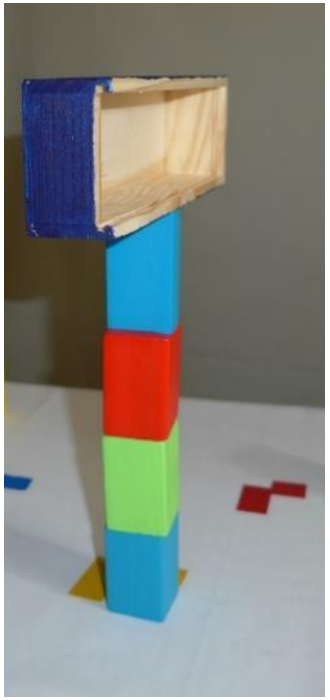
10. Left and Backwards

Challenge Number	Order Performed	Direction controls provided	Structure Type	Location	Arm start Position (software)	X, y Coords	Position of tower (marker colour)
10	13	Left/Right Forwards/Backwards	Tower	Left-Backwards	Left-Backwards	10, 9, 90	Blue Left Back

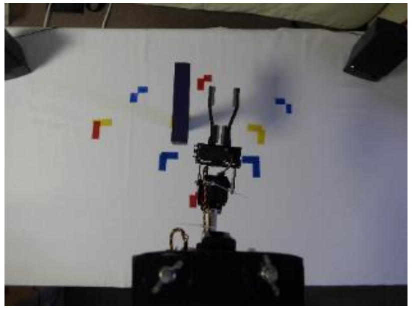
Interface	Position of tower	Alternative view
		
Starting position		
Right side view	Above	
		

11. Left and Down

Challenge Number	Order Performed	Direction controls provided	Structure Type	Location	Arm start Position (software)	X, y Coords	Position of tower (marker colour)
11	10	Left/Right Up/Down	Tower	Left-Down	Left-Down	2, 8, 90	Yellow-Left

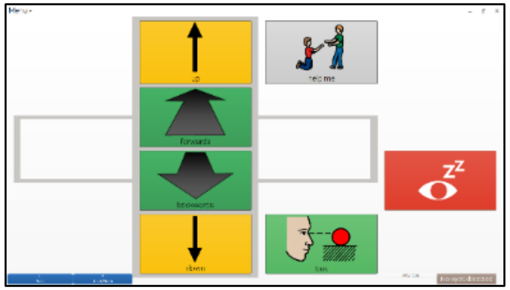
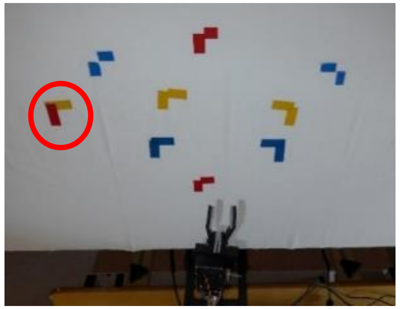
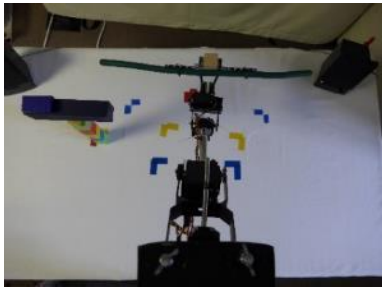
Interface	Position of tower	Alternative view
		

Starting position

Right side view	Above
	

12. Up and Backwards (stick)

Challenge Number	Order Performed	Direction controls provided	Structure Type	Location	Arm start Position (software)	X, y Coords	Position of tower (marker colour)
12	18	Forwards/Backwards Up/Down **** Remember to grip ****	Tower	Backwards-Up	Backwards-Up	8, 11, 90	Red-Yellow (Left)

<table>
<tr><th>Interface</th><th>Position of tower</th><th>Alternative view</th></tr>
<tr><td></td><td></td><td rowspan="5">N/A</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2">Starting position</td></tr>
<tr><td>Right side view</td><td>Above</td></tr>
<tr><td></td><td></td></tr>
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13. Right and Forwards

Challenge Number	Order Performed	Direction controls provided	Structure Type	Location	Arm start Position (software)	X, y Coords	Position of tower (marker colour)
13	11	Left/Right Forwards/Backwards	Tower	Right Forwards	Right-Forwards	4, 7, 90	Blue- Right- Forward

<table>
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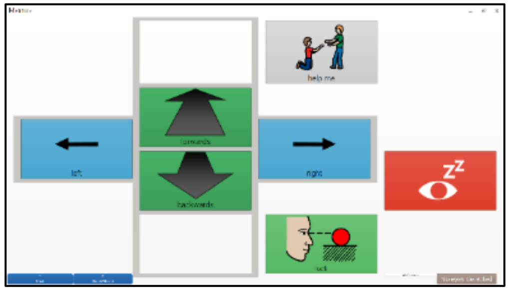
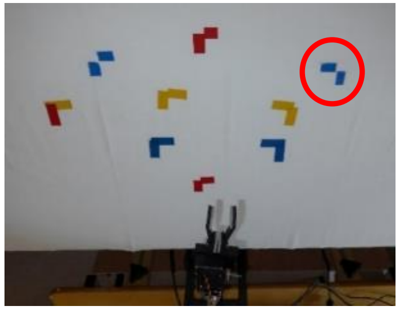
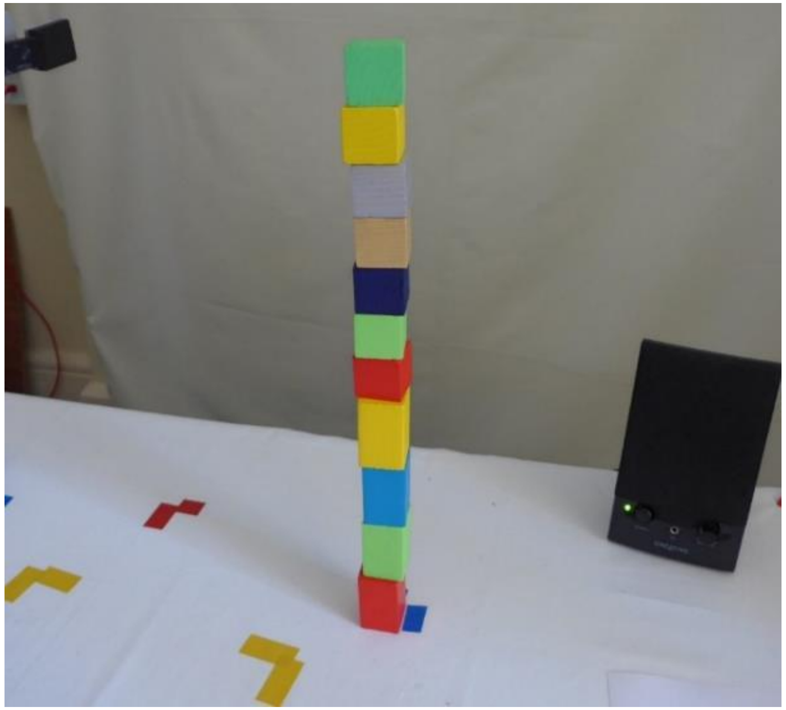
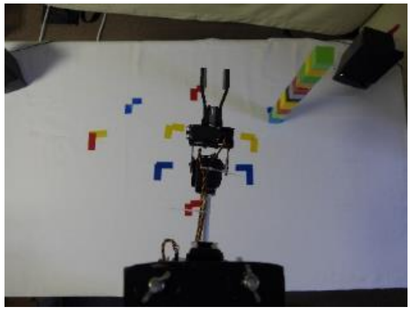
<tr><td></td><td></td><td rowspan="4"></td></tr>
<tr><th colspan="2">Starting position</th></tr>
<tr><th>Right side view</th><th>Above</th></tr>
<tr><td></td><td></td></tr>
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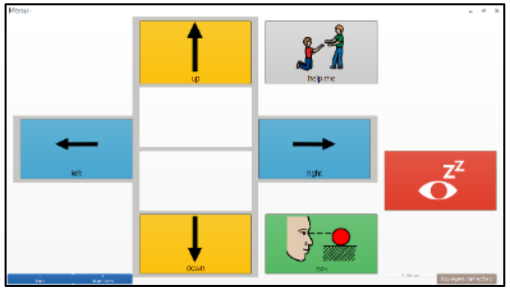
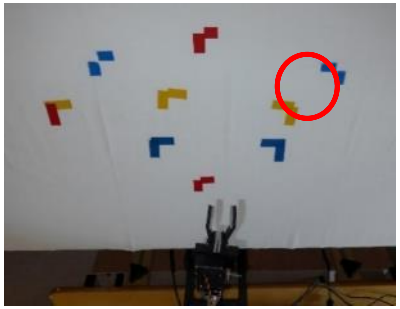
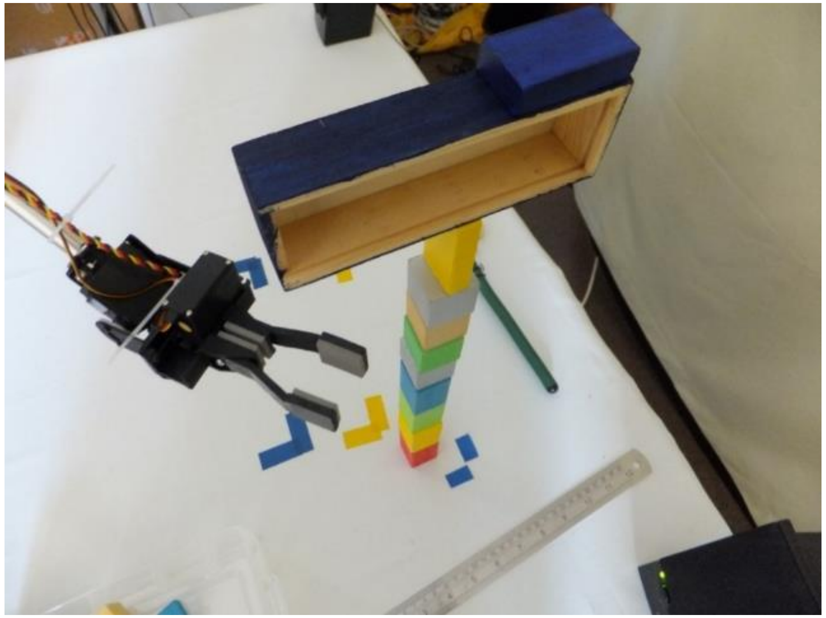
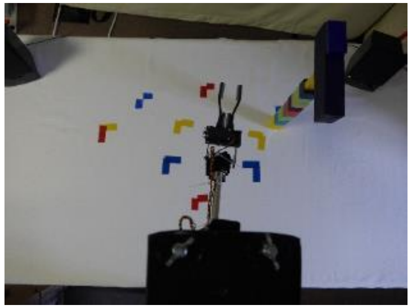
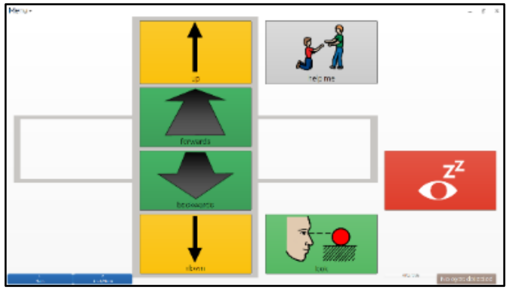
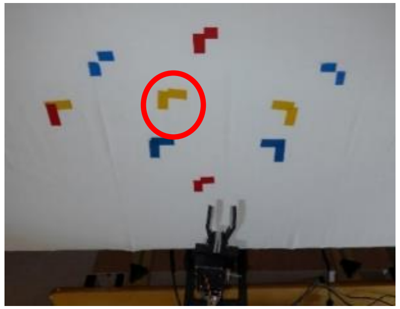
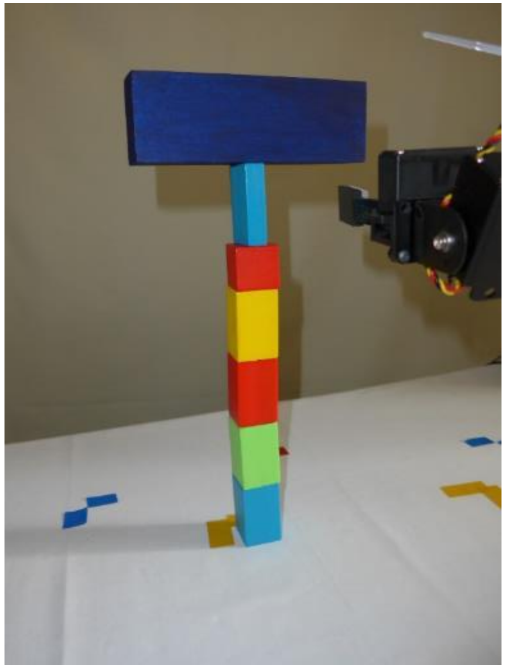
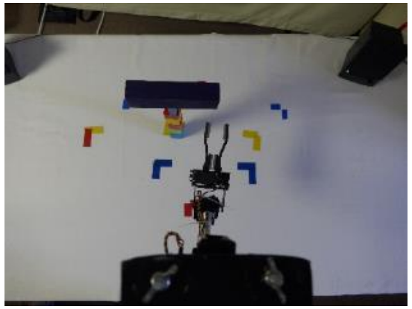
14. Right and Up

Challenge Number	Order Performed	Direction controls provided	Structure Type	Location	Arm start Position (software)	X, y Coords	Position of tower (marker colour)
14	15	Left/Right Up/Down	Tower	Right Up	Right-Up	4, 11, 90	Between Yellow-Right-Forward & Blue-Right-Forward

Interface	Position of tower	Alternative view
		
Starting position		
Right side view	Above	
		

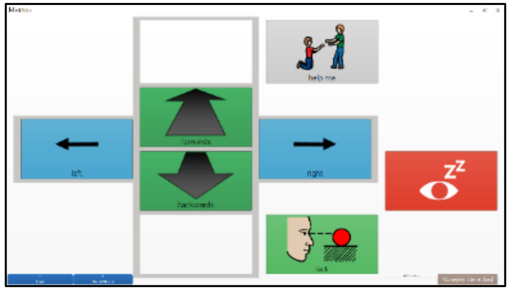
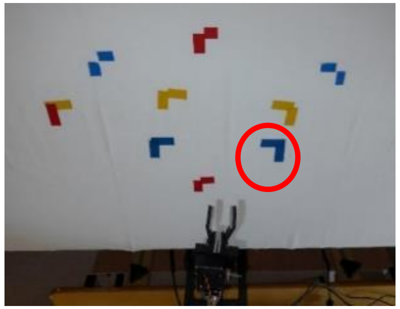
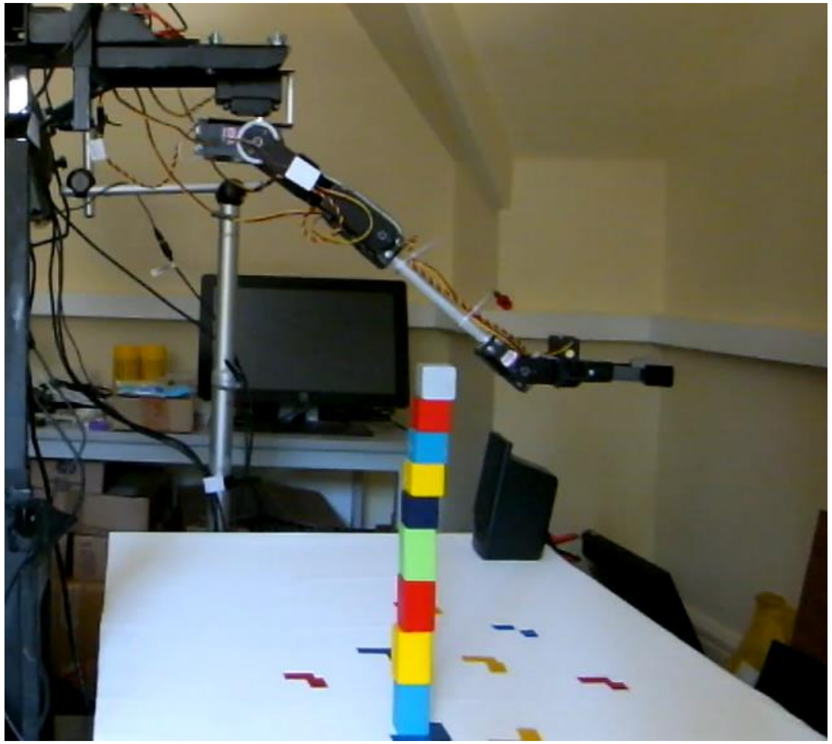
15. Forwards and Up

Challenge Number	**Order Performed**	**Direction controls provided**	**Structure Type**	**Location**	**Arm start Position (software)**	**X, y Coords**	**Position of tower (marker colour)**
15	12	Forwards/Backwards Up/Down	Tower	Forwards Up	Forwards-Up	1, 12, 90	Yellow-Left

Interface	Position of tower	Alternative view
		
Starting position		
Right side view	Above	
		

16. Right and Backwards

Challenge Number	Order Performed	Direction controls provided	Structure Type	Location	Arm start Position (software)	X, y Coords	Position of tower (marker colour)
16	14	Left/Right Forwards/Backwards	Tower	Right Backwards	Right-Backwards	10, 9, 90	Blue- Right- Back

<table>
<tr><th>Interface</th><th>Position of tower</th><th>Alternative view</th></tr>
<tr><td></td><td></td><td rowspan="4"></td></tr>
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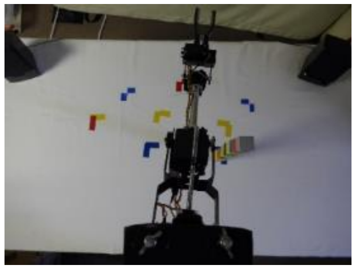
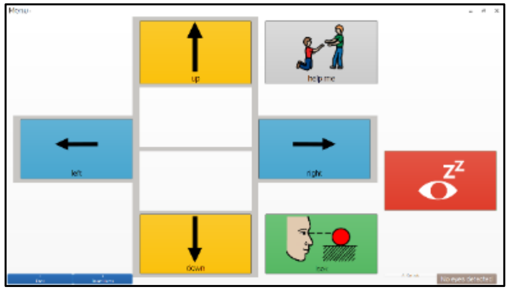
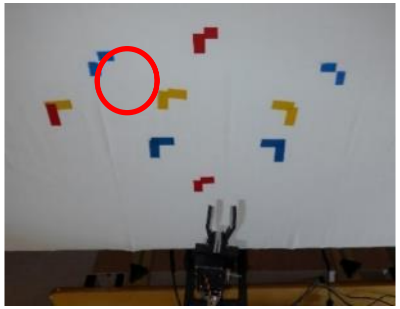
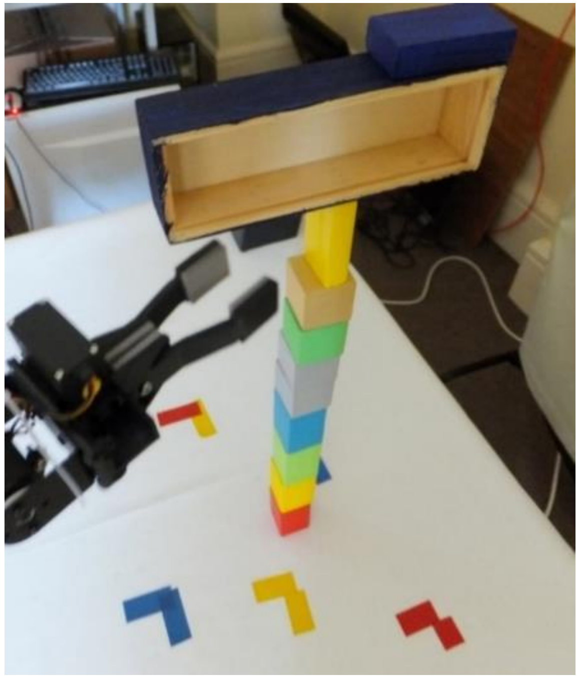
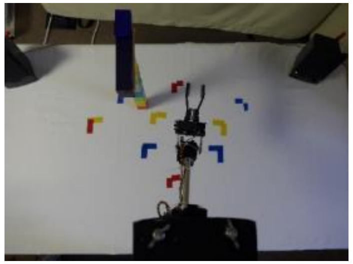
<tr><th>Right side view</th><th>Above</th></tr>
<tr><td></td><td></td></tr>
</table>

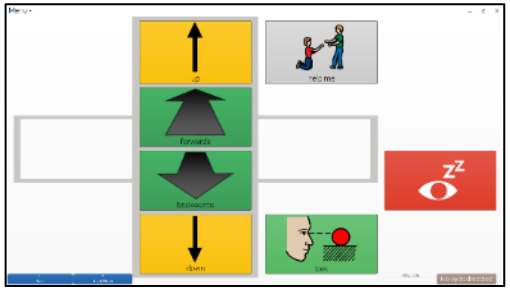
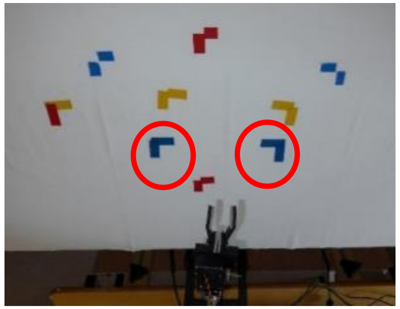
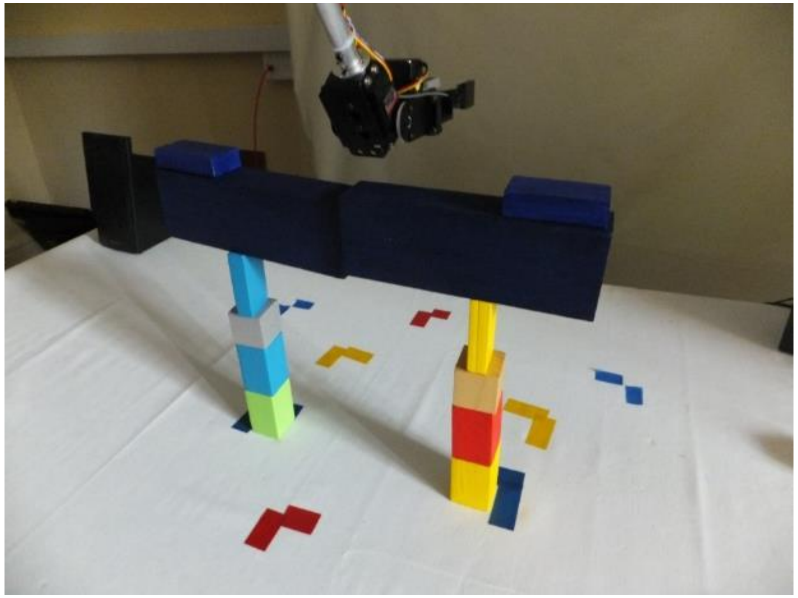
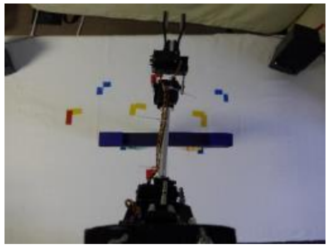
17. Left and Up

Challenge Number	Order Performed	Direction controls provided	Structure Type	Location	Arm start Position (software)	X, y Coords	Position of tower (marker colour)
17	16	Left/Right Up/Down	Tower	Left Up	Left-Up	4, 11, 90	Between Yellow-Left-Forward & Blue-Left-Forward

Interface	Position of tower	Alternative view
		
Starting position		
Right side view	Above	
		

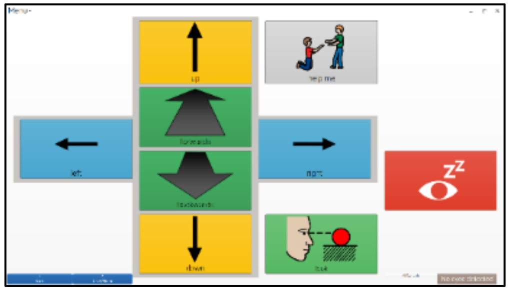
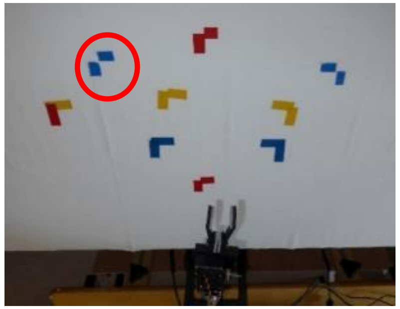
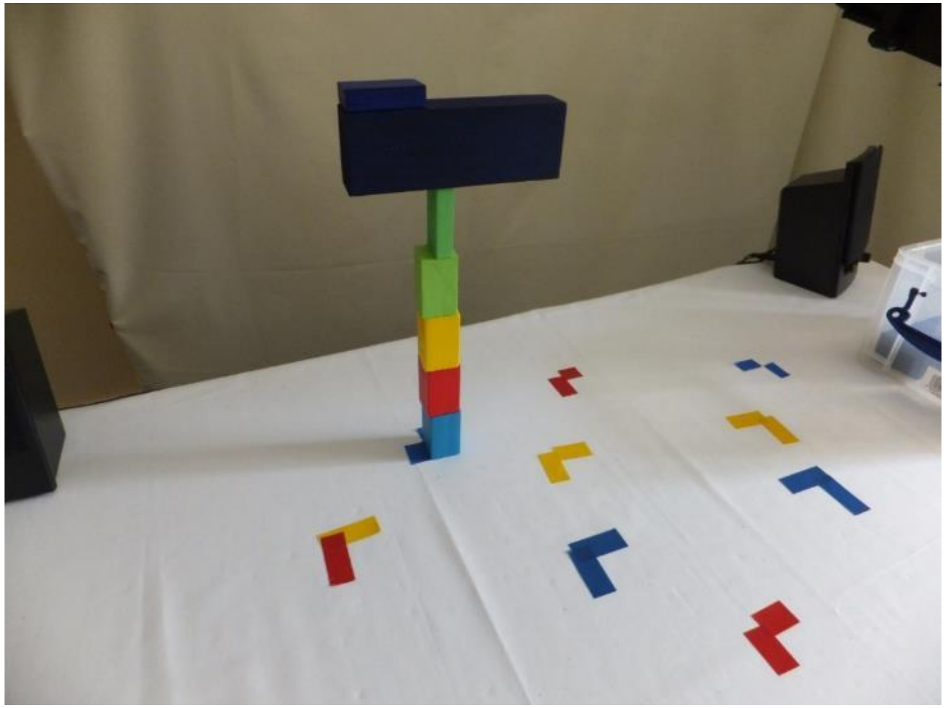
18. Backwards and Down

Challenge Number	Order Performed	Direction controls provided	Structure Type	Location	Arm start Position (software)	X, y Coords	Position of tower (marker colour)
18	17	Forwards/Backwards Up/Down	Arch	Backwards Down	Backwards-Down	8, 7, 90	Blues-Back

Interface	Position of tower	Alternative view
		
Starting position		
Right side view	Above	
		

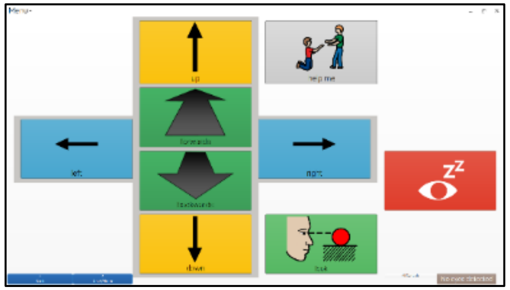
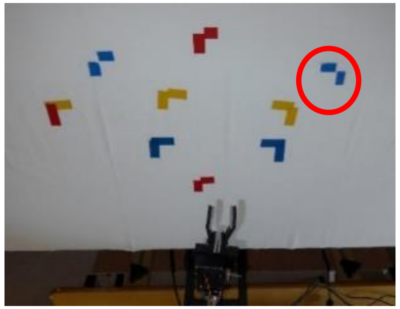
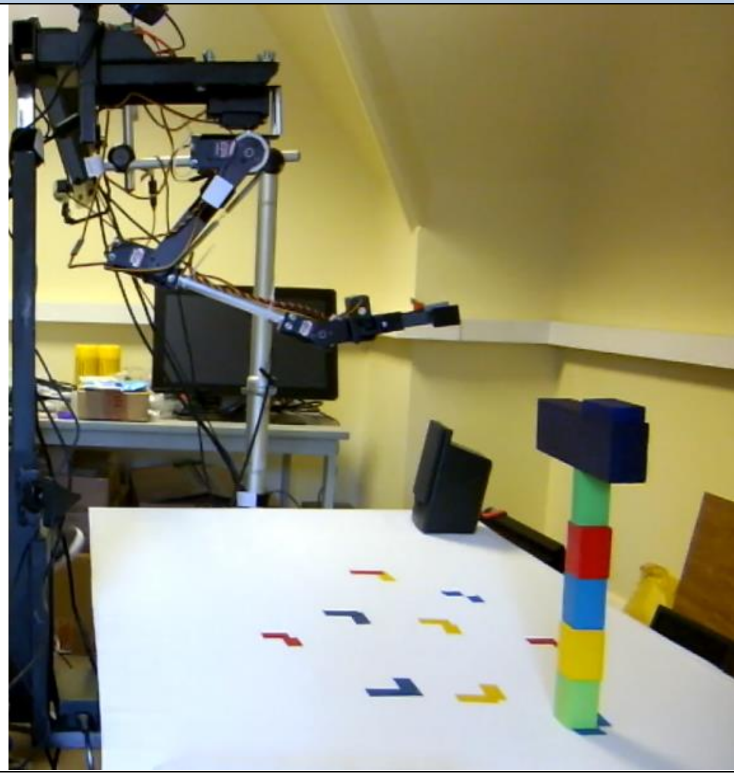
19. Left and Forwards and Down

Challenge Number	**Order Performed**	**Direction controls provided**	**Structure Type**	**Location**	**Arm start Position (software)**	**X, y Coords**	**Position of tower (marker colour)**
19	19	All Controls Left/Right Up/Down Forwards/Backwards	Tower	Left Forwards Down	Left-Forwards-Down	2, 8, 90	Blue- Left- Forward

Interface	Position of tower	Alternative view
		
Starting position		
Right side view	Above	
		

20. Right and Forwards and Down

Challenge Number	Order Performed	Direction controls provided	Structure Type	Location	Arm start Position (software)	X, y Coords	Position of tower (marker colour)
20	20	All Controls Left/Right Up/Down Forwards/Backwards	Tower	Right Forwards Down	Right-Forwards-Down	2, 8, 90	Blue- Right- Forward

<table>
<tr><th>Interface</th><th>Position of tower</th><th>Alternative view</th></tr>
<tr><td></td><td></td><td rowspan="4"></td></tr>
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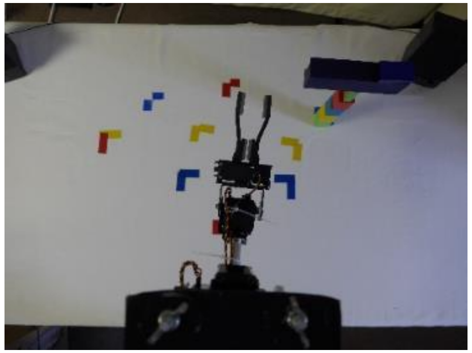
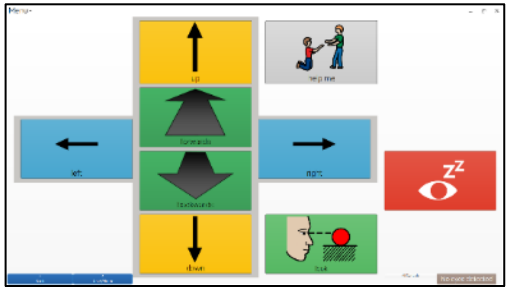
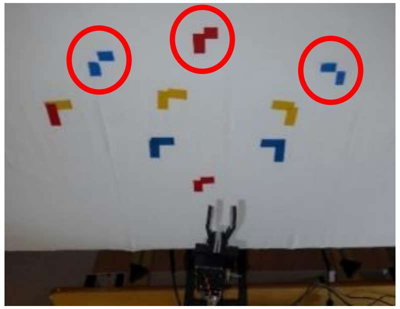
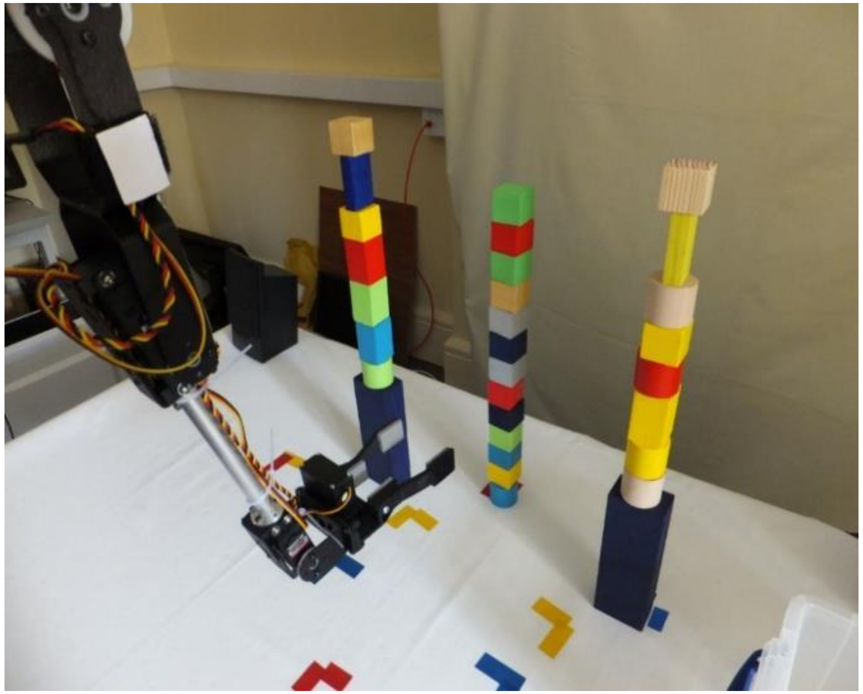
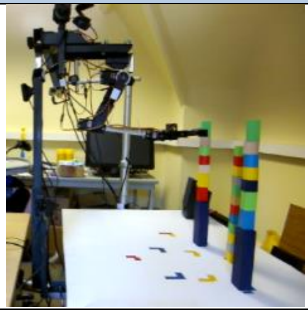
<tr><td></td><td></td></tr>
</table>

24. 3 Towers

Challenge Number	Order Performed	Direction controls provided	Structure Type	Location	Arm start Position (software)	X, y Coords	Position of tower (marker colour)
24	21	All Controls Left/Right Up/Down Forwards/Backwards	3 Towers		Left & Right Back Back	4, 7, 90	1. Blue-Left-Forward 2. Red-Forward 3. Blue-Right-Forward

Interface	Position of tower	Alternative view
		
Starting position		
Right side view	Above	
		

Appendix X Ethical Approval, PIS and PAF

Ethical Approval

Bournemouth University

Research Ethics Checklist

Reference Id	7197
Status	Approved
Date Approved	19/02/2016

Researcher Details

Name	Mark Moseley
School	Media School
Status	Postgraduate Research (MRes, MPhil, PhD, DProf, DEng)
Course	Postgraduate Research
Have you received external funding to support this research project?	No
Please list any persons or institutions that you will be conducting joint research with, both internal to BU as well as external collaborators.	Victoria Education Centre, Poole, Dorset

Project Details

Title	The use of technology to provide physical interaction experiences for cognitively able young people who have complex physical disabilities
Proposed Start Date of Data Collection	31/01/2016
Proposed End Date of Project	02/10/2018
Original Supervisor	Ethics Programme Team
Approver	Ethics Programme Team

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Summary - no more than 500 words (including detail on background methodology, sample, outcomes, etc.)
Background/Introduction:Young people who have severe physical disabilities and good cognition may face many barriers to learning and education, communication, personal development, physical interaction and play experiences. Physical interaction and play are known to be important components of child development, but this group currently has few appropriate ways in which to have such opportunities. Technology can help facilitate such experiences. This research aims to develop a technology-based solution to provide this group with the potential for physical interaction, exploration and physical play, in order to develop their knowledge of spatial and real-world physical concepts. This solution will utilise eye-gaze technology, robotics and haptic feedback (artificial sensation).Research site & Researcher's credentials:The research site will be Victoria Education Centre (VEC) in Poole, Dorset which is a Special Education establishment for children and young people aged 3-19. I have been employed as an Assistive Technologist at VEC for the past nine years. I hold a current Enhanced DBS certificate for working at VEC. VEC was recently graded as an 'Outstanding' school by OFSTED.Sampling technique:The target group will be identified using a convenience sampling method i.e. convenient to the researcher. The total population will be comprised of the pupils who currently attend VEC. The target group or intended sample population will be a subset of the total population. This subset will be small (n <= 5) and will be comprised of those VEC pupils who have both severe physical disabilities and 'good' cognition.Additionally, it is also intended that there will be staff participants and more able-bodied pupils who will take part in the project in order to inform the design and test the resultant solution.Methodology:A mixed methods methodology will be used i.e. both quantitative and qualitative data will be gathered during the study. Individual case studies will be used to gather experiential data from the participants. Data gathering techniques used will include observation, interviews and surveys. Video recordings of sessions will be used for later analysis.User Centred Design principles will be used to develop the proposed solution.The solution will be implemented in sections and then evaluated in three stages: 1. By staff participants; 2. By more-able VEC pupils who are able to provide verbal feedback; 3. The target group. This process is to ensure that the solution is reliable and meets requirements before being used by the target group.The project will be divided into a series of work packages including the following: development of the haptic technology module; haptic experiments; development of the eye gaze module; combined haptic and eye gaze experiments; development of the robotic module; consolidation of haptic, eye gaze and robotic modules; experiments involving the complete solution i.e. comprising of the haptic, eye gaze and robotic modules.Outcomes:It is anticipated that this research will produce a working prototype solution which will provide the potential for the participants to experience physical activities. It is predicted that the use of this solution will improve the participant's knowledge of physical and spatial concepts.

External Ethics Review

Does your research require external review through the NHS National Research Ethics Service (NRES) or through another external Ethics Committee?	No

Research Literature

Is your research solely literature based?	No

Human Participants

Will your research project involve interaction with human participants as primary sources of data (e.g. interview, observation, original survey)?	Yes

Does your research specifically involve participants who are considered vulnerable (i.e. children, those with cognitive impairment, those in unequal relationships—such as your own students, prison inmates, etc.)?	Yes
Is a DBS check check required?	Yes
Does the study involve participants age 16 or over who are unable to give informed consent (i.e. people with learning disabilities)? NOTE: All research that falls under the auspices of the Mental Capacity Act 2005 must be reviewed by NHS NRES.	No
Will the study require the co-operation of a gatekeeper for initial access to the groups or individuals to be recruited? (i.e. students at school, members of self-help group, residents of Nursing home?)	Yes
Will it be necessary for participants to take part in your study without their knowledge and consent at the time (i.e. covert observation of people in non-public places)?	No
Will the study involve discussion of sensitive topics (i.e. sexual activity, drug use, criminal activity)?	No

Are drugs, placebos or other substances (i.e. food substances, vitamins) to be administered to the study participants or will the study involve invasive, intrusive or potentially harmful procedures of any kind?	No

Will tissue samples (including blood) be obtained from participants? Note: If the answer to this question is 'yes' you will need to be aware of obligations under the Human Tissue Act 2004.	No

Could your research induce psychological stress or anxiety, cause harm or have negative consequences for the participant or researcher (beyond the risks encountered in normal life)?	Yes
Will your research involve prolonged or repetitive testing?	Yes
Will the research involve the collection of audio materials?	No
Will your research involve the collection of photographic or video materials?	Yes
Will financial or other inducements (other than reasonable expenses and compensation for time) be offered to participants?	No

Please explain below why your research project involves the above mentioned criteria (be sure to explain why the sensitive criterion is essential to your project's success). Give a summary of the ethical issues and any action that will be taken to address these. Explain how you will obtain informed consent (and from whom) and how you will inform the participant(s) about the research project (i.e. participant information sheet). A sample consent form and participant information sheet can be found on the Research Ethics website.

Vulnerable Participants:This study will involve participants who are considered vulnerable i.e. young people who have complex physical disabilities. This group is the focus of this research as they have few opportunities to engage in physical activities. The main aim of this research is to help to address this need.Informed consent/Gatekeeper:Informed consent will be requested from both VEC pupils and their parents/guardians, as well as staff participants.I have an existing working relationship with many of the pupils at VEC. In order to avoid a 'power-imbalance', a gatekeeper (Sarah Gilling - Head of the Speech and Language therapy department at Victoria Education Centre (VEC)) has been appointed. Sarah will request informed consent from pupil participants using a specially designed PIS and informed consent form. Sarah is a highly skilled communicator and will supplement this PIS with explanations using a variety of communication techniques suited to each participant's needs, such as sign language and the use of pictorial symbols.Risk of harm:Every effort will be made to ensure the safety and wellbeing of participants. There may be a small risk that some of the participants experience sensitivity to certain aspects of the haptic elements of experiments.To mitigate against this risk: prototypes will have been thoroughly tested; participants will be introduced to the technology in stages, starting with the mildest sensations; there will always be a member of staff present who is attuned to the participant's communication method. If the participant appears to react adversely, the experiment will be stopped immediately.In addition to BU's ethical standards, this research will also be governed by VEC's working practices and codes of conduct.The room where the research experiments will take place is within the school's buildings and is familiar to all of the participants. This room is subject to regular Health and Safety inspections by approved inspectors within the school. There is an emergency call system located nearby.Prolonged/repetitive testing:Participants may be asked to perform tasks several times during a session. Pupil participants may have shorter attention spans than adults, for example. To limit this risk, sessions may be shortened or split, as required.Photographic/video materials:Video recordings will be made which can be analysed retrospectively. It will also provide a visual record of progression.I will be heavily involved as a participant observer during experiments and so will have little opportunity to make notes whilst also guiding participants, dealing with the technical aspects and demands of the experiments.The majority of the target group use electronic speech generating devices to communicate verbally. During experiments, they will use these devices to control the solution, reducing their capacity to also communicate verbally. Recording sessions will allow the capture of non-verbal communication and the 'user-experience'.Summary of ethical issues and preventative measures:The data gathered during this study will be stored securely at VEC, either on a restricted area of the school's computer network, and/or within locked storage. Where appropriate, data will be securely encrypted and password protected.

Final Review

Will you have access to personal data that allows you to identify individuals OR access to confidential corporate or company data (that is not covered by confidentiality terms within an agreement or by a separate confidentiality agreement)?	No
Will your research involve experimentation on any of the following: animals, animal tissue, genetically modified organisms?	No
Will your research take place outside the UK (including any and all stages of research: collection, storage, analysis, etc.)?	No

Please use the below text box to highlight any other ethical concerns or risks that may arise during your research that have not been covered in this form.

Other information:I have official written permission from Simon Brown (Head teacher of Victoria Education Centre) to carry out my research at the school.The following documents are attached to this application:•A combined PIS and PAF designed for use with the target group•A PIS for parents/legal guardians of the target group•A PIS for VEC employee participants•A PAF for parents/legal guardians•A PAF for VEC employees•A formal permission letter from VECThese documents will be adapted as necessary to suit the needs of each potential participant.

Participant Information Sheet (PIS) - Parents and Legal Guardians

Participant Information Sheet - Parents and Guardians

1. The title of the research project

Using technology to enable young people who have complex physical disabilities to operate a robotic arm, in order to experience physical control and have contact sensations in their hands and fingers.

2. Invitation

Your child is being invited to take part in a University research study. This forms part of an Engineering Doctorate (EngD) (see: https://www.epsrc.ac.uk/skills/students/coll/engdoctorate/) being undertaken by Mark Moseley at Bournemouth University. Mark has been employed by Victoria Education Centre (VEC) as an Assistive Technologist for the past ten years.

Before you decide whether you would like your child to take part it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask if there is anything that is not clear, or if you would like more information. Take time to decide whether or not you wish your child to take part.

Your child will also be asked whether they wish to take part, but only if you consent to their taking part

3. What is the purpose of the project?

Intellectually able young people who have complex physical disabilities often have limited ways in which they can experience physical activities, including play. This can hinder their development and learning. This research study aims to develop a technology-based solution (referred to as "the solution") which can be used by such young people to engage in physical activities. The study will run from January 2017 until October 2018.

4. Why has my child been chosen?

Your child has been chosen because they have complex physical disabilities which restrict their ability to take part in physical activities.

Three other VEC pupils are being invited to take part.

5. Does my child have to take part?

It is up to you to decide whether or not you wish your child to take part. If you do decide that they should take part you will be given this information sheet to keep and be asked to sign a Participant Agreement Form (PAF). If you decide that your child should take part you are still free to withdraw them from the study at any time (up to the point where the data are processed and become anonymous, so that their identity cannot be determined) without giving a reason. Deciding not to take part, or withdrawing from the project will not impact upon your child's right to any treatment services, education or further opportunities in any way.

6. What do I have to do? What will happen to my child if I agree that they can take part?

If you agree to your child taking part in the study, they may be involved for a period spanning up to two years from January 2017.

Your child's involvement will typically be in blocks, periodically taking part in individual sessions lasting around 30 - 45 minutes. These sessions will help to shape the design of the solution and also help to develop your child's understanding of physical concepts. Your child will have numerous opportunities to use the solution. The sessions will usually take place at Victoria Education Centre. You will be consulted if this ever needs to change.

The solution will involve a combination of various technologies including eye gaze, robotics, and haptic (artificial sensation) equipment.

Please note: The solution will have been extensively tested by VEC staff before your child uses it.

Your child will be monitored carefully while using the solution. They will be asked how they feel about it and have the opportunity to contribute to improving its design.

The sessions will be run by Mark Moseley (the researcher). There will always be at least one other member of staff present during the sessions. This member of staff may be a teaching assistant or therapist/therapy assistant.

7. What are the possible disadvantages and risks of my child taking part?

It is not expected that there will be any disadvantages and risks from taking part.

The research will sometimes involve attaching 'wearable' electronic technology to your child, but there will be no danger to your child. There will be wires and your child may be given mild artificial sensations in their hands and fingers to give them a feeling e.g. of grasping an object, or reaching a boundary. There may be a small chance that your child experiences sensitivity to certain aspects of the haptic (artificial sensation) elements of the solution.

The activities will always be explained to your child and they will be asked whether they want to take part in a particular activity. If your child appears to be distressed at any point, the session will be stopped immediately.

Please be assured that your child's wellbeing is of the highest importance.

8. What are the possible benefits of my child taking part?

Your child will have the opportunity to use and shape the solution being developed, which could help them and other similar young people. It is hoped that the experiences will contribute to their development, be fun and involving, as well as educational.

9. Will my child's taking part in this project be kept confidential? What will happen to the results of the research project?

Your child will be observed and video recordings made. Notes in both written and electronic form will also be made. All of the information collected during the course of the research will be kept strictly confidential in a secure location at VEC. Your child will not be able to be identified in any reports or publications.

This research has been approved by Bournemouth University's Research Ethics Panel and will adhere to strict ethical guidelines. Victoria Education Centre's child protection policies will also be observed at all times.

10. What type of information will be sought from my child and why is the collection of this information relevant for achieving the research project's objectives?

Your child will be observed using the solution and asked how they feel about it. This information will be used to further improve the solution so that your child can use it as well as is possible.

11. Will my child be recorded, and how will the recorded media be used?

Video recordings will be made of your child using the solution. These will be used to analyse how well the solution performs and will help to decide where modifications need to be made to improve it. The recordings will also provide a video diary of your child's progress when using the solution. The recordings may be used to demonstrate the solution to others but, if this is required, further permission will be sought from you.

The video recordings of your child's activities made during this research will be used only for analysis and for illustration in conference presentations and lectures. No other use will be made of them without your written permission, and no one outside the project will be allowed access to the original recordings.

12. Who is organising/funding the research?

This research forms part of an Engineering Doctorate (EngD) which is administered by Bournemouth University (BU). The researcher is based within the Centre for Digital Entertainment (CDE) which forms part of the Faculty of Media and Communication. The researcher is funded by the Engineering and Physical Sciences Research Council (EPSRC) and the CDE.

BU Bournemouth University CDE Centre for Digital Entertainment EPSRC Engineering and Physical Sciences Research Council

Researcher: Mark Moseley Assistive Technologist at Victoria Education Centre and Engineering Doctorate (EngD) candidate.

13. Contact for further information

To find out more, please contact:

Name:	Mark Moseley
Position:	Assistive Technologist/Postgraduate Researcher
Address:	Victoria Education Centre 12 Lindsay Road, Poole, Dorset, BH13 6AS.
Telephone Number:	01202 758 338 (Wednesdays 11:00 – 16:00 term-time only)
Email address:	mmoseley@victoria.poole.sch.uk mmoseley@bournemouth.ac.uk

Name:	Dr Leigh McLoughlin
Position:	Lecturer and lead supervisor
Address:	Bournemouth University Talbot Campus, Fern Barrow, Poole, Dorset, BH12 5BB.
Telephone Number:	01202 965 505 (Please ask for Leigh)
Email address:	lmcloughlin@bournemouth.ac.uk

14. If you need to make a complaint:

Please contact the Research Ethics Coordinator:

Name:	Professor Iain MacRury
Position:	Deputy Dean - Research and Professional Practice (Faculty of Media and Communication)
Address:	Weymouth House W128, Talbot Campus, Fern Barrow, Poole, Dorset, BH12 5BB.
Telephone Number:	01202 962 465
Email address:	imacrury@bournemouth.ac.uk

15. Final information

You will be given a copy of this participant information sheet (PIS) to keep. If you decide that you would like your child to take part, you will also be given a copy of the signed Participant Agreement Form (PAF) to keep.

Thank you for taking the time to read through this information.

Mark Moseley

Participant Agreement Form (PAF) - Parents and Legal Guardians

Participant Agreement Form – Parents and Legal Guardians

Full title of project: Using technology to enable young people who have complex physical disabilities to operate a robotic arm, in order to experience physical control and have contact sensations in their hands and fingers.

Name, position and contact details of researcher:
Mark Moseley - EngD Candidate (Postgraduate Researcher) – Centre for Digital Entertainment and Victoria Education Centre, 12 Lindsay Road, Poole, Dorset, BH13 6AS.
01202 758 338 (Wednesdays 11:00 – 16:00 only)
mmoseley@victoria.poole.sch.uk
mmoseley@bournemouth.ac.uk

Name, position and contact details of supervisor (if the researcher is a student):
Dr Leigh McLoughlin – Lead Supervisor and Lecturer at Bournemouth University
Bournemouth University, Poole House P324, Talbot Campus, Fern Barrow, Poole, BH12 5BB
lmcloughlin@bournemouth.ac.uk

	Please Initial or Tick Here
I have read and understood the Participant Information Sheet (PIS) for the above research project.	
I confirm that I have had the opportunity to ask questions.	
I understand that my child's participation is voluntary.	
I understand that I am free to withdraw my child up to the point where the data are processed and become anonymous.	
During the research project, I am free to withdraw my child without giving reason and without there being any negative consequences.	
Should I not wish my child to answer any particular question(s) or complete a test, I am free to decline on their behalf.	
I give permission for members of the research team to have access to my child's anonymised responses. I understand that their name will not be linked with the research materials, and that they will not be identified or identifiable in the outputs that result from the research.	
I agree to my child being featured in any film taken during the project.	
I agree to my child taking part in the above research project.	

____________________ __________ ________________________

Name of Parent / Guardian   Date   Signature

____________________ __________ ________________________

Name of Researcher   Date   Signature

This form should be signed and dated by all parties after the participant receives a copy of the participant information sheet and any other written information provided to the participants. A copy of the signed and dated participant agreement form should be kept with the project's main documents which must be kept in a secure location.

Participant Agreement Form (PAF) (Parents and Legal Guardians) v1.0.docx

Participant Information Sheet (PIS) - VEC Employees

Participant Information Sheet – Victoria Education Centre Employees

1. The title of the research project

Using technology to enable young people who have complex physical disabilities to operate a robotic arm, in order to experience physical control and have contact sensations in their hands and fingers.

2. Invitation

You are being invited to take part in a University research project. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask if there is anything that is not clear, or if you would like more information. Take time to decide whether or not you wish to take part.

3. What is the purpose of the project?

Intellectually able young people who have complex physical disabilities often have limited ways in which they can experience physical activities, including play. This can hinder their development and learning. This research study aims to develop a technology-based solution which can be used by such young people to engage in physical activities. The study will run from September 2016 until October 2018.

4. Why have I been chosen?

You have been chosen because you are an employee of Victoria Education Centre (VEC), and have expressed an interest in participating in this research study. You may work regularly with one or more of the young people who will be invited to take part in this research study. It is anticipated that approximately five VEC pupils will take part. Other members of VEC staff are also being asked to take part.

5. Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep (and be asked to sign a Participant Agreement Form). You can still withdraw up to the point where the data are processed and become anonymous, so that your identity cannot be determined. If you decide to withdraw, you do not have to give a reason. This decision will not affect you adversely in any way. Also, it will not affect any VEC pupil's treatment, care or education.

6. What do I have to do? What will happen to me if I take part?

Your involvement in this study will vary depending upon your job role at VEC but, broadly speaking, may involve one or more of the following:

- Taking part in experiments which will later be carried out with VEC pupils;

- Trialling the solutions generated by the research and providing feedback;
- Periodically attending sessions with a pupil once or twice a week for a number of weeks (7-10). Each session will last for approximately 30-45 minutes;
- Providing information about the pupils' abilities;
- Assisting with the sessions e.g. helping the researcher (Mark Moseley) to attach equipment, working collaboratively with the pupil;
- Supporting the pupil during sessions;
- Ensuring that the pupil is comfortable and being aware of signs of discomfort;
- Providing encouragement;
- Assisting with communication;
- The researcher will ask for your opinions about the sessions - your feedback will be highly valuable to this research.

The research will take place in the Environmental Control room on the top floor of Carmel House at VEC.

The researcher's name is Mark Moseley. Mark has worked for VEC for the past 10 years as an Assistive Technologist.

7. What are the possible disadvantages and risks of taking part?

There should be no risks to you. There may be a small chance that VEC pupils experience sensitivity to certain aspects of the haptic (artificial sensation) elements of the solution. As someone who knows them well, you may be able to identify such situations more easily.

8. What are the possible benefits of taking part?

Whilst there may be few direct benefits to you personally, taking part may help you to develop a deeper understanding of pupils' abilities.

It is anticipated that this research will benefit the pupils who take part in the following ways:

- Development of their spatial awareness abilities;
- Education - Learning new ideas, improving their knowledge of the physical world.

9. Will my taking part in this project be kept confidential? What will happen to the results of the research project?

All of the information collected about you during the course of the research will be kept strictly confidential. You will not be able to be identified in any reports or publications.
The results of this research may appear in academic publications. If you wish, a copy of these will be made available to you.

Please be aware that the data may be used for further research beyond this study.

10. What type of information will be sought from me and why is the collection of this information relevant for achieving the research project's objectives?

You are likely to have greater knowledge of individual pupils than the researcher, as you may work with them regularly. As a result of this, you may notice things that are not apparent to the researcher.

The information that you provide will help to identify the pupils' abilities and progress. This will also help to improve the technology.

11. Will I be recorded, and how will the recorded media be used?

Any video recordings made during this research will be used only for analysis and for illustration in conference presentations and lectures. No other use will be made of them without your written permission, and no one outside the project will be allowed access to the original recordings.

12. Who is organising/funding the research?

This research forms part of an Engineering Doctorate (EngD) which is administered by Bournemouth University (BU). The researcher is based within the Centre for Digital Entertainment (CDE) which forms part of the Faculty of Media and Communication. The researcher is funded by the Engineering and Physical Sciences Research Council (EPSRC) and the CDE.

Researcher: Mark Moseley Assistive Technologist at Victoria Education Centre and Engineering Doctorate (EngD) candidate

13. Contact for further information

To find out more, please contact:

Name:	Mark Moseley
Position:	Postgraduate Researcher
Address:	Victoria Education Centre 12 Lindsay Road, Poole, Dorset, BH13 6AS.
Telephone Number:	01202 758 338 (Wednesdays 11:00 – 16:00 only)
Email address:	mmoseley@victoria.poole.sch.uk mmoseley@bournemouth.ac.uk

Name:	Dr Leigh McLoughlin
Position:	Lecturer and Lead Supervisor
Address:	Bournemouth University Fern Barrow Talbot Campus Poole Dorset, BH12 5BB
Telephone Number:	01202 965 505 (Please ask for Leigh)
Email address:	lmcloughlin@bournemouth.ac.uk

14. If you need to make a complaint:

Please contact the Research Ethics Coordinator:

Name:	Professor Iain MacRury
Position:	Deputy Dean - Research and Professional Practice (Faculty of Media and Communication)
Address:	Weymouth House W128, Talbot Campus, Fern Barrow, Poole, Dorset, BH12 5BB
Telephone Number:	01202 962465
Email address:	imacrury@bournemouth.ac.uk

15. Final information

You will be given a copy of this Participant Information Sheet (PIS) to keep. If you decide that you would like to take part, you will also be given a copy of the signed Participant Agreement Form to keep.

Thank you for taking the time to read through this information.

Mark Moseley

Participant Agreement Form (PAF) - VEC Employees

Participant Agreement Form – VEC Staff

Full title of project: Using technology to enable young people who have complex physical disabilities to operate a robotic arm, in order to experience physical control and have contact sensations in their hands and fingers.

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During the research project, I am free to withdraw without giving reason and without there being any negative consequences.	
Should I not wish to answer any particular question(s) or complete a test, I am free to decline.	
I give permission for members of the research team to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the outputs that result from the research.	
I agree to be featured in any film taken during the project.	
I agree to take part in the above research project.	

____________________ __________ ____________________

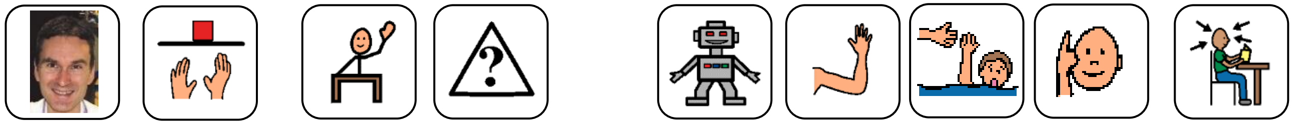
Name of Participant Date Signature

____________________ __________ ____________________

Name of Researcher Date Signature

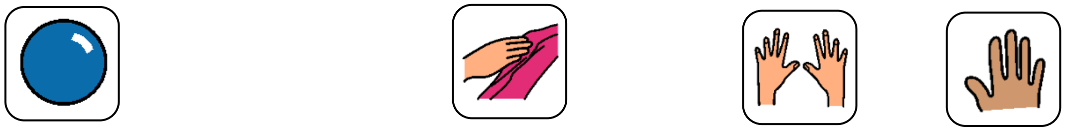
This form should be signed and dated by all parties after the participant receives a copy of the participant information sheet and any other written information provided to the participants. A copy of the signed and dated participant agreement form should be kept with the project's main documents which must be kept in a secure location.

Symbolised Participant Information Sheet (PIS) and Participant Agreement Form (PAF) (combined) for PPs

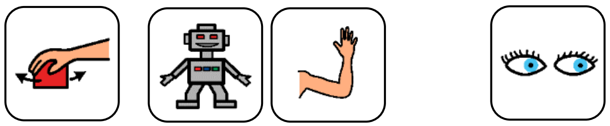


Mark wants to know how using a robot arm helps you to learn.

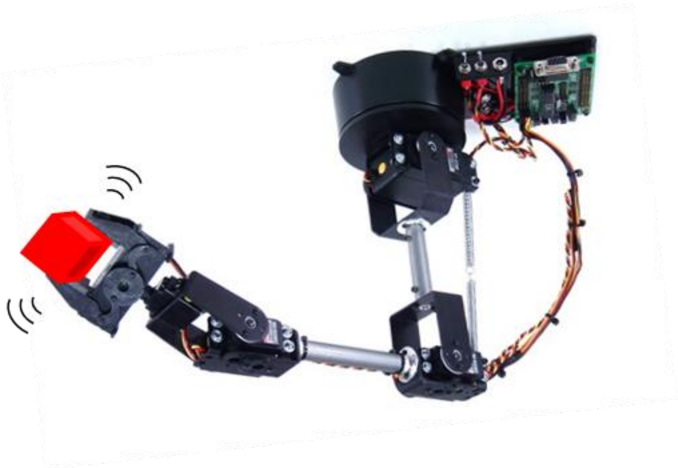
How can you help?

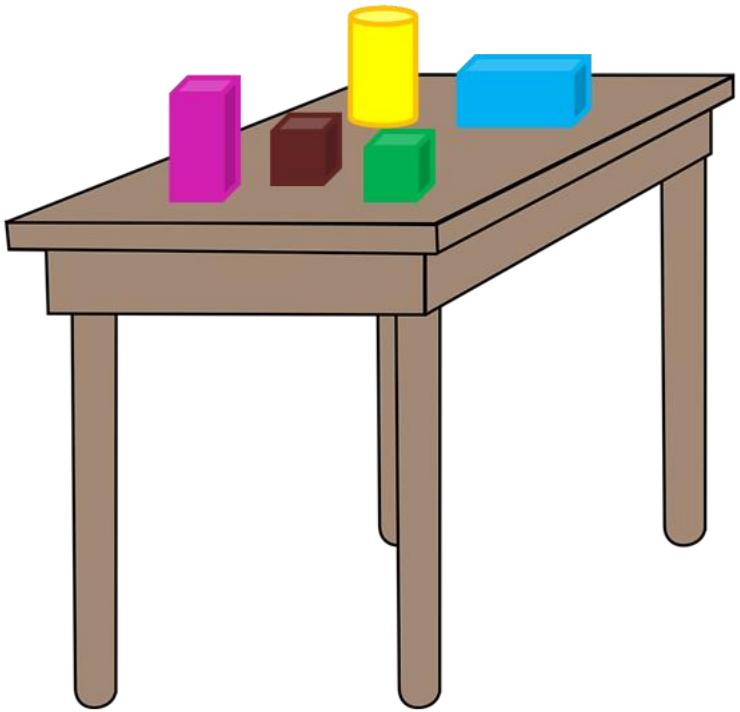


1. **Wear something that will send sensations to your hands and fingers**



2. **Move a robot arm using eye-gaze**

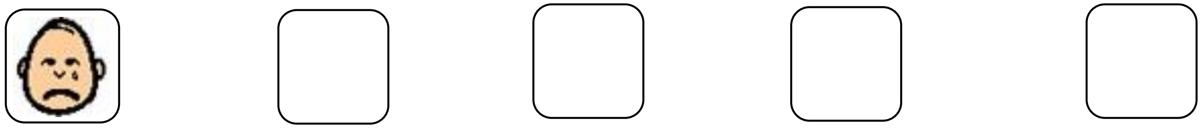




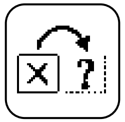
Photograph courtesy of Helen Oakley:

http://www.smartboxat.com/2012/09/helen-oakley-tobii-eye-

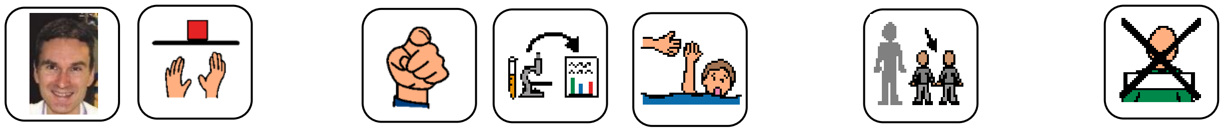
You can stop taking part at any time.



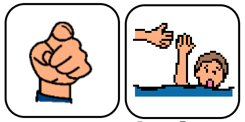
If you are unhappy, talk to [name], [name], [name] or [name] (Safeguarding team)



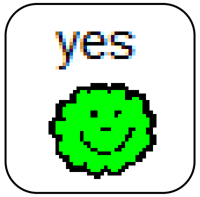
<u>What next?</u>

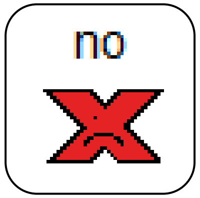


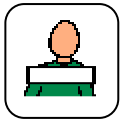
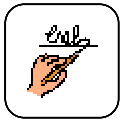
Mark wants to use your results to help other children. Your name will not be used.



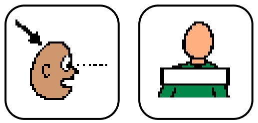
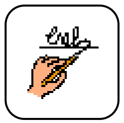
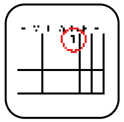
<u>Can you help?</u>





Name and Signature of participant (or VEC staff member/parent/carer/guardian/ where appropriate)

Witness' name.. Title....................... Signed .... Date............................

Participant's name: ……………………………………………………………………..

Consent taken by: ……………………………………………………………………….

Location: …………………………………………………………………………………..

Signature: …………………………………………………………………………………

Position: ……………………………………………………………………………………

Date: ………………………………………………………………………………………

Others present: ……………………………………………………………………………

Consent verified by: ………………………………………………………………………

Verification method: e.g. Yes/No questions, eye-pointing, VOCA, other:

………………………………………………………………………………………………..

This combined PIS and PAF uses Mayer Johnson's BoardMaker PCS symbols
This combined PIS and PAF is based upon one created by Nicola Mearing (Speech & Language Therapist – VEC) – used with kind permission
Robotic arm image: http://www.lynxmotion.com/images/hi-res/al5d2.jpg and photograph courtesy of Helen Oakley: http://www.smartboxat.com/2012/09/helen-oakley-tobii-eye-gaze/

Appendix Y Cognitive Assessments: administration instructions

Y.1 Static image-based assessment instructions

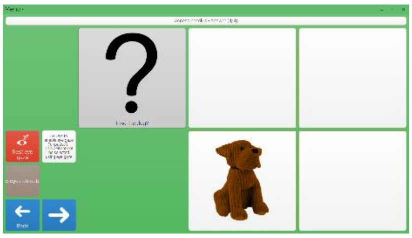
Preparation

1. Run Grid 3
2. Load: 'Mark's Research – Assessments' – 'Cognitive Assessment (Spatial + positional concepts)'

Therapist Information

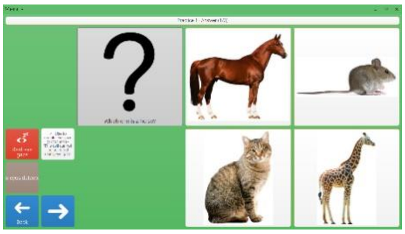
The assessment is in 3 parts:

a) An **access check** – to ensure that the pupil participant can access all of the answer cells:

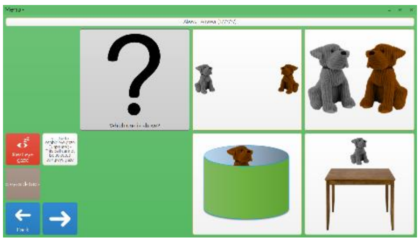


Note: If the participant is not able to successfully complete the access check, please seek technical assistance.

b) A **practice** – to help the participant understand how the 'quiz' works and what is required of them:



c) The actual **assessment ('quiz'):**



Explanation for the pupil participant

“The computer will ask you some questions”

“You will see some cells on the screen”

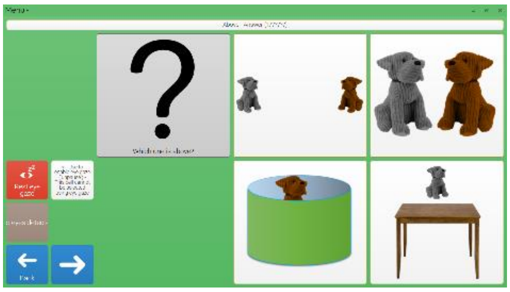
“You will then hear a question, and be asked for an answer”

“First we will check that you can reach all of the answer cells on the screen”

“We will then do some practice questions”

“and then we will do the quiz”

Instructions for therapist



1. Say “Here is the question”.
2. Press the  cell.
3. Say “Look at all of these cells” <**Point to all of the answer cells**> “and look at me when you are ready to give your answer” (repeat as needed).
4. Say “Here is the question again”.
5. Press the  cell again.
6. Say “Please select your answer”.
7. Un-pause eye gaze  to allow the participant to give their answer.
8. The next question will then appear.

Y.2 Video-based assessment instructions

Explanation to the pupil participant

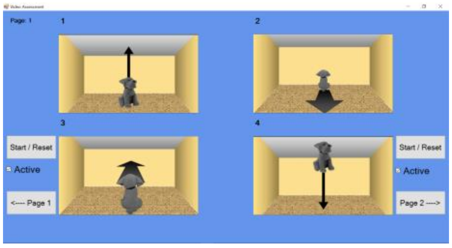
"I'm going to ask you to look at some videos."

"The videos will appear here" <**Point to the black 'empty' cells on the screen**>

"I will then ask you a question about the videos."

"I then want you to answer the question by looking at the one video that you think is the answer."

"You can look at the videos for as long as you want"



Therapist Information

The pupil cannot select their answers – they can only stare at them.

The first four questions relate to Page 1, the next four to Page 2. When changing to the second page, let the participant know that the videos are different.

Process

1. Select the [Start / Reset] button.
2. Move to the correct page (1 or 2) as indicated by the question, using [<---- Page 1] and [Page 2 ---->]
3. Say "Here are the videos".
4. Say "Look at and watch all of the videos for as long as you want and then look at me when you are ready to hear the question".
5. If not ticked, tick [☑ Active] to enable eye gaze and let them study the videos.
6. When the participant looks at you:
   - Say "Which one is…." <Question>
   - Say "Now look at the videos again and when you are ready to give your answer look at me".
7. When the participant looks at you:
   - Repeat the question "Which one is…"
   - Say "Please look only at your answer"
8. If the answer is unclear, say "Did you mean that one?"
9. Note down their answer (1 – 4) on the sheet.
10. Say "Are you ready to go on to the next question?"