DOCTOR OF ENGINEERING (ENGD)

Towards Effective Virtual Reality Environments for the Behavioural Assessment of Executive Dysfunction

Lyons, Zack

Award date:
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submitted by

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for the degree of Doctor of Engineering

of the

University of Bath

Centre for Digital Entertainment
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Abstract

Human-computer interaction is concerned with understanding the goals of people in a target domain, documenting their motivations and challenges to ground investigations into how technology can be used to support their interactions. In this thesis, the domain of interest is that of neurobehavioural rehabilitation services for people with executive dysfunction arising from acquired brain injuries. For the clinical professionals and users of such services, the predominant goal is the reacquisition of functional and socio-cognitive skills to facilitate successful community reintegration.

The gold standard in assessing and training executive skills is to place someone in community settings, to facilitate observation of their behaviours, strategies and emergent deficits. However, this comes with practical difficulties: such activities are irregular, costly and uncontrollable. Virtual reality uses immersive and interactive experiences to psychologically engage users in situations that are impractical to re-create in the real world. It aligns with the goals of neurobehavioural rehabilitation, which seeks to familiarise and observe the behaviours of service users in ecologically valid situations.

In this thesis, we report on user-centred design research conducted with the Brain Injury Rehabilitation Trust to ensure our approach is theoretically sound and practicable. Through analysis of the literature and in situ observations we present an understanding of clinical activities framed through human-computer interaction, to establish clinically grounded frameworks to support clinician-service user interactions. These inform the development of an experimental platform, Virtuality Street, to demonstrate how virtual environments can expose key behavioural correlates of executive dysfunction and facilitate clinical observations of service users.

Having developed an experimental platform that is grounded in clinical practice, we present a lab-based study with neurotypical participants to demonstrate Virtuality Street's capacity to deliver challenges that are executive in nature, and support the devising of strategies to complete socio-cognitive and functional tasks. We further report on demonstration sessions with clinical professionals involved in acquired brain injury rehabilitation, and three service users approaching the end of their rehabilitative programme. The feedback from these groups support the overarching goal of this clinically motivated research, which is to build towards clinical validation of Virtuality Street as a therapeutic tool.

Acknowledgements

Over the 8 years of this degree, there have been too many friends, colleagues and acquaintances for me to list and acknowledge in their entirety. However, there have been two constants present throughout that time. Dr Leon Watts has been my mentor for nearly a decade and offered patience, counsel and friendship both within and outside of this research. Thank you Leon for helping me when I was stuck, for pushing me when I was ready to give up, for giving me kind words in times of difficulty and hard words when I needed to hear them. I would also never have made it through this project without my family – Nina, Paul and Josh – who supported this ambition from the day I voiced it through to the day I completed it.

I would like to thank Prof Nigel Harris for making this project possible and for his guidance throughout as my industrial supervisor. I am also deeply grateful to Dr Sara da Silva Ramos and Dr Brian O'Neill for their input and mentorship, and for driving the collaborations described in this thesis.

I wish to acknowledge the funding for this project, which was provided by the EPSRC and Disabilities Trust. This research was a partnership between the Centre for Digital Entertainment, Designability, and the Brain Injury Rehabilitation Trust. I would like to extend my heartfelt thanks to all those in these organisations who gave their time and expertise towards this research.

Contents

Chapter 1

Introduction

1.1 Thesis Overview

This thesis addresses the opportunities afforded by virtual reality simulations to assist clinical therapists in their cognitive rehabilitation work, primarily in the domain of acquired brain injuries (ABIs). An estimated 350,000 people in the UK are admitted to hospital each year with an acquired brain injury, which can occur through trauma, degenerative condition, or other causes (Headway, 2021c). The effects of an ABI are wide ranging, with physical, cognitive or behavioural consequences for the person affected. The longevity and severity of these effects can vary greatly between survivors, with some people being able to resume their lives with minimal intervention after the acute treatment of their injuries. In its severest instances, people require rehabilitation for several months or years after their injury.

ABIs frequently affect frontal lobe areas associated with both higher cognitive functioning and a variety of socio-behavioural competences. Taken together, these impairments of “executive functioning” can have a prolonged and profound impact on the group of cognitive processes responsible for monitoring and regulating behaviour. The resulting deficits can present interpersonal, functional and vocational difficulties that have a direct impact on someone’s ability to manage relationships, live independently, and perform daily living activities. Rehabilitation is necessary to treat the cognitive deficits and teach strategies to overcome difficulties and re-gain independence.

Precisely how executive dysfunction affects a person’s behaviour is highly variable and difficult to predict. Humans by their nature are terrifically diverse and this compounds the varying effects an ABI can have on someone. It is essential for clinical professionals to understand how someone will behave in a variety of settings outside of the hospital, such as to tailor rehabilitation and deliver interventions that will assist them in their road to recovery and eventual return to the community. The successful assessment and rehabilitation of executive functions is a critical determinant of community re-integration (Sohlberg and Mateer, 2001).

The gold standard of assessment to support clinical understanding of behaviour is observation in situ. The ability to witness people in a naturalistic setting undertaking real tasks enables clinicians to make accurate inferences about the cognitive determinants of their behaviour and informed decisions on rehabilitation. However, such assessments are difficult to control and lack repeatability; a sought-after behaviour, such as how to deal with a specific situation, may not be exhibited during a given assessment. They can be difficult to observe and record without compromising on the desired natural and unobtrusive settings. Assessments are also costly in time, money and resources, and as such are carried out infrequently.

A further complication is that, in some cases, the implications of ABIs are so severe that rehabilitation is enforced, including detainment under the Mental Health Act, to prevent harm to either the person affected or the people around them. This “challenging behaviour” may make it hazardous for clinicians to take someone out of the hospital for much of their rehabilitation, reducing any opportunities to practice everyday tasks such as catching a bus or visiting the shops. Where this behaviour occurs in a hospital, a clinical response may be to temporarily withdraw access to the community, thus preventing the desired assessments from taking place. In other people this behaviour may not manifest in a hospital environment but can appear at inopportune and hazardous times during community assessments. There is an inherent risk taken when assessing anyone with executive dysfunction or challenging behaviour out of the hospital, and when weighed up by clinicians this may impede efforts to rehabilitate someone for community re-integration. Although the gold standard is to observe someone in naturalistic community settings, in reality this often lacks practicality.

Virtual reality (VR) technologies have seen increasingly prevalent use in serious (non-gaming) applications, including in therapy and rehabilitation. Its core strengths are in placing users in virtual environments that are analogues of settings that are either impossible or difficult to re-create in the real world, or that might be too costly or dangerous to do so. The resurgence of VR over the past decade has largely revolved around the use of gaming technology to drive the development of good quality head-mounted displays (HMDs). Lag-free, full visual field HMDs with head tracking to synchronise first-person perspective with a user’s movement can give users a feeling of immersion – a sense of being in the environment. By delivering audiovisual stimuli and matching movement around a room to what is seen in the HMD, VR can prompt reactions and behaviours that mirror those exhibited in real settings. What's more, VR has become affordable and visible in the public domain, becoming a staple feature of technology exhibitions and facilitating uptake. VR is a powerful technology that has the potential to simulate real world scenarios in a realistic, safe and believable way.

In this thesis, we explore how virtual reality can support rehabilitation activities and deliver meaningful benefits to people involved with acquired brain injury rehabilitation. Our research stems from the following two premises:

- The successful rehabilitation of executive dysfunction requires assessments of how someone behaves in real world settings.
- Virtual reality is capable of simulating real world scenarios safely and sufficiently to inspire realistic behaviour.

This thesis is examining how VR scenarios can exercise cognitive faculties known to be implicated in executive functioning such that relevant observations of a person's abilities and limitations may be made. It presents the design and development of a virtual reality environment for the assessment of executive dysfunction, and sets out to achieve five goals:

1. To explore the types of assessments conducted in clinical practice for the rehabilitation of executive dysfunction, including their purpose, strengths and limitations.
2. To iteratively design and develop a virtual reality environment prototype that we expect to have meaningful use in a therapeutic programme by echoing aspects of clinical assessments.
3. To determine the efficacy of a virtual reality environment to observe behaviours associated with executive functions in both neurotypical people and those with acquired brain injuries.
4. To gather feedback on the utility and validity of a virtual reality environment from clinical professionals.
5. To present design guidelines for the future development of virtual reality environments for acquired brain injuries.

Our work uses a combination of literature surveys, in situ observations of clinical practice, prototype development, neurotypical user testing, and feedback from end users and clinical practitioners. We have a steadfast approach to include clinical professionals throughout the realisation, design and development of a virtual reality environment, such as to foster a strong working relationship, trust in the technology, and validated research outputs. Our commitment is reflected by our engagement with domain experts and service users, which is made possible through a multidiscipline collaboration with our research partners.

1.2 Collaborations

This engineering doctoral research is a collaboration between designers of assistive technology at Designability, clinical professionals at the Brain Injury Rehabilitation Trust, and a lecturer and research engineer at the Centre for Digital Entertainment at the University of Bath.

1.2.1 Designability

Based at the Royal United Hospital in Bath, Designability (formerly Bath Institute of Medical Engineering) is a charity with a long history in developing assistive technologies. With a diverse team of designers, engineers and therapists, Designability takes a holistic and user-centred approach to producing bespoke solutions for end users with a wide range of illnesses and disabilities. The charity engages in original research to help them tackle real world problems and works with commercial partners to ensure that research outputs can positively affect the lives of people in need. Prof Nigel Harris, Chief Executive of Designability throughout this research until January 2019, facilitated the collaborations in this research and was industrial supervisor for the project. Dr Praminda Caleb-Solly, Head of Electronics and Computer Systems at Designability until November 2018, advised on technology and research methods. Design experience and exposure to user-centred techniques was kindly provided by other staff at Designability, which housed the research engineer periodically through the first few years of the project.

1.2.2 Brain Injury Rehabilitation Trust

The original idea for this project came from clinical professionals at the Brain Injury Rehabilitation Trust (BIRT), a service provider within the Disabilities Trust charity. BIRT is a European specialist in providing neurobehavioural rehabilitation for people with acquired brain injuries, and has 13 specialist hospitals across the UK (Disabilities

Trust, 2021b). The hospitals' "service users" typically live on-site, receiving round-the-clock residential care with varying degrees of independence. BIRT's mission is to provide people with the functional skillset to safely return to independent living. Our research is strengthened by the clinical expertise of domain experts from BIRT. Dr Brian O'Neill, a consultant neuropsychologist, has provided mentoring in neuropsychological rehabilitation techniques. Dr Sara da Silva Ramos, Research Fellow with the Disabilities Trust, has given frequent feedback and validation to design ideas, and has ensured that our work has remained grounded in theory and conversant with research ethics, methods and rehabilitation practices. Dr Ohr Barak gave vital early input to the project and facilitated site visits until his departure from BIRT.

We wish to gratefully acknowledge that partial funding for this project was provided by the Disabilities Trust through BIRT, and to offer our appreciation to the numerous clinical professionals who have given their time and expertise to this research.

1.2.3 Centre for Digital Entertainment

The Centre for Digital Entertainment (CDE) is an EPSRC-funded collaboration between the University of Bath and Bournemouth University. As a Centre for Doctoral Training, the CDE supports research engineers in performing applied research in collaboration with companies across the UK, developing close partnerships with industry to produce research outputs that have a direct benefit to end users. The CDE actively works with departments from within its respective universities, which for this research includes the Department of Computer Science at the University of Bath and the department's Human Computer Interaction (HCI) research group. Dr Leon Watts, senior lecturer in the Department of Computer Science and researcher in the HCI group, has been the academic supervisor and provided his expertise in the design and evaluation of interactive systems to facilitate social cognition.

Funding for this project has been primarily provided by the EPSRC through the CDE.

1.3 Definitions

In this section we define some key terminology and concepts that will be used throughout this thesis. This list is not intended to be comprehensive, and further terms will be defined as appropriate.

Acquired Brain Injury (ABI)

ABI refers to any injury sustained by the brain after birth, such as through trauma or stroke.

Traumatic Brain Injury (TBI)

Brain injuries caused by trauma, such as from a car crash or a fall, are known as TBIs. Some sources use this term synonymously with ABI, but we categorise it as a subset of ABIs.

Executive Functions/Executive Functioning

Executive functioning is an umbrella term for the group of cognitive processes responsible for regulating behaviour (Sohlberg and Mateer, 2001). If the components of behaviour can be thought of as building blocks, the executive functions are the processes that pieces them together.

Executive Dysfunction

When the executive functions are impaired, typically through injury to the frontal lobes, a person may struggle to perform tasks, be organised, or think creatively or critically. This is known as executive dysfunction. Some sources (Wilson et al., 1996) use the term Dysexecutive Syndrome (DES), referring to the multitude of symptoms that can arise from executive dysfunction (Headway, 2021b), however in contemporary literature it is common to use the term executive dysfunction.

Clinical Professionals

Rehabilitation of ABIs is a multidisciplinary effort requiring diverse teams of specialists. Neuropsychologists, occupational therapists, physiotherapists, and speech and language therapists are amongst those involved, but many other professionals, such as support workers, are involved in care and rehabilitation. We may refer to individuals or groups of specialists in this thesis, but when generally talking about those who work with people with ABIs, we use the term clinical professionals.

Service Users

Many terms are used to describe people with acquired brain injuries in rehabilitative settings. We have found “patient” to be used sparsely, with clinical professionals often using the term “client” or “service users”, where people use a service provided by the Brain Injury Rehabilitation Trust. We typically use the term service users in this thesis.

Neurotypical

In this thesis we require a way to distinguish between people with and without ABIs.

For the former we generally use the term “service users”. Some sources (Alderman et al., 2003) describe people without ABIs as “neurologically healthy”. To encourage positive language, the National Autistic Society (2019) suggests using the term “neurotypical” in place of normal, and this has gone on to be used to describe people free from cognitive or neurological impairments. We therefore will be using this term to describe people without ABIs.

Activities

Rehabilitation consists of activities – events that take place involving at least one person with an ABI and clinical professional(s). Rehabilitation activities are any activity that is designed to assess a person with a brain injury, to allow them to practice performing tasks, or to train them to perform those tasks. Activities can also be designed to allow people to do things that they find comforting, or to do daily living activities such as chores. We use “designed”in a very loose, non-systematic sense here; activities are used to plan and provide structure to a service user’s day. For much of this thesis, activities are rehabilitation exercises for assessment or therapy.

Tasks

Although tasks and activities seem synonymous in language, we define an activity as being made up of one or more tasks. Tasks are typically used within the context of rehabilitation activities, where a task is given by a clinical professional and has some associated criteria for how well it is performed.

1.4 Thesis Scope

This thesis reports an investigation of the potential for virtual reality environments to support the rehabilitation of acquired brain injuries. We have alluded to the fact that the characteristics of ABIs are something of an oxymoron, in that they are so varied and unpredictable in nature that a typical “set of characteristics” is difficult to define. An ABI in one person can manifest an entirely different set of symptoms and challenges than for another person. As such it is necessary to define a scope for this thesis.

Although we have received input from various clinical professionals through conferences and demonstrations, most of our interaction with domain experts has come from the Brain Injury Rehabilitation Trust (BIRT). In particular, staff at two of BIRT’s hospitals have provided guidance and validation to the ideas presented in this thesis. The service users we have interacted with at these hospitals are real people, and regardless of how representative they are of the broader brain injury population, we see any work and input regarding their rehabilitation as an enormously worthwhile endeavour. However, we must consider the generalisability of our work and acknowledge that these service users exemplify some of the challenges faced by people recovering from ABIs. Similarly, any input from clinical professionals is framed by experience, which we cannot expect to always cover the full diversity of people with an ABI.

Clinical professionals at BIRT, including neuropsychologists, occupational therapists and speech and language therapists, have kindly given considerable time towards this project. However, they are entrusted with the safety and wellbeing of the service users in their care, and it is the foremost responsibility of these professionals to ensure that any therapeutic tool is appropriate before use. Access to service users was controlled by consultant neuropsychologists. In particular, the use of VR by service users (Chapter 8) came after the VR environment had gone through a BIRT ethical review, had been tried and approved by a consultant neuropsychologist, and a careful selection was made of appropriate service users who were close to discharge.

We are also fortunate to have the support of clinical partners who see the potential of technology in their future work. Many of the inputs we report on in this thesis are from clinical professionals who want to see this technology succeed. This is not to demean their input, but rather to recognise it as enthusiastic and to acknowledge that more may need to be done to persuade end-users of its utility.

Finally, a note on the technical scope of this project. The current innovations in virtual reality could be said to come from the gaming industry, which has created tools to enable individuals to develop and publish their own VR applications. This has been of great benefit to us, in that a single research engineer has been able to create a VR environment for this project. However, most polished and high-fidelity VR experiences still require teams of experienced developers working on the visual and audio assets. The scope of this project is not to create a finished product with studio quality, but to develop a working prototype to test ideas and contribute to design knowledge.

In summary, the scope of this thesis is to:

- Validate ideas and gather input from BIRT clinical professionals.
- Work with carefully selected BIRT service users who are close to discharge.
- Develop a prototype virtual reality environment to test design ideas for rehabilitation.

1.5 Research Methodology

A core tenet of our research methodology is the inclusion of clinical professionals to prompt and validate ideas that contribute to the development of a virtual reality environment. This process serves multiple purposes. Firstly, we have a duty as HCI researchers to seek informed and domain-specific input when working within a setting foreign to that of our own, and where end-users have established and efficacious practices in place. We make no claims to possess first-hand experience administering ABI rehabilitation or to have any formal training in clinical practice. As such, we are wholly obliged to gather domain-specific knowledge from experts in this field, and to be upfront with respect to our knowledge when conversing with clinical professionals and other interested parties.

Similarly, it is outright essential to convey ideas from within computer science to clinical professionals. It is our responsibility not only to communicate what is achievable within the current state of technology, but to be transparent – even forward – with engineering and research processes. This communication is aimed at raising awareness and acceptability of technologies amongst clinical professionals and inspiring thoughts as to how their work may be enhanced. It enhances trust between clinical professionals and both the HCI researchers and technology being developed, and it gives them input into developing technology they want to use. It also demonstrates our commitment to supporting clinical professionals in their work, not replacing them or pretending to know better. Furthermore, it manages expectations of what can be achieved and what might be developed through research. Both inspiring thought and managing expectations are paramount in such collaborations, even when there is a variance between the two. The inspiration to create something that is not yet achievable is what drives the further research and development of technology, to better answer the problems thrown up by applied practice.

Most importantly though, the inclusion of clinical professionals in this research builds upon the bridge between the worlds of HCI and ABI rehabilitation. Through this collaboration there has been a path of joint discovery, as researchers and neuropsychologists have worked together to define a problem and refine it through iterative prototype development. This relationship has enabled us to explore the potential for virtual reality described in this thesis, where each discovery and realisation – whether positive or negative – has been made jointly and with meaning to both HCI research and clinical practice.

Consequently, the design ideas contributing to development of a virtual environment in this thesis have been subjected to an iterative process:

- A practice or occurrence is read in literature, is observed in situ, or is remarked upon by a clinical professional.
- Its significance in rehabilitation practice is studied.
- Its potential for being realised in a virtual reality environment is considered.
- Its utility is discussed between researchers and clinical professionals.
- Where appropriate, it contributes to the implementation of a feature in a virtual reality.
- Feedback has been sought on its utility.

Following this process means that all design guidelines of a virtual reality environment should originate from existing clinical practice. In other words, no element of the virtual environment should be foreign to clinical professionals. Activities with clinical professionals have enabled this process and sought to ensure that this research is grounded within ABI rehabilitation. By incorporating clinical practice in this way, we believe that a virtual environment should, in principle, integrate with and complement existing rehabilitation practices.

1.6 Research Ethics

This research has included witnessing, talking to, and conducting observations of people who are undergoing rehabilitation, and asking them to use technology for the purpose of gathering feedback from themselves or clinicians. The ethical concerns of working with this population, and within this domain, have been an important consideration throughout the project. As described in Section 1.5, our collaboration with clinical professionals has been central to this research, including to these ethical considerations. The collaboration has helped to develop a mutual trust between us as HCI practitioners and clinical professionals as domain experts, as well as to provide us with confidence that we are working within the bounds of what is ethically appropriate and routine in this domain.

Our ethical considerations were broadly focused around two aspects of the research. Firstly, our involvement with Brain Injury Rehabilitation Trust service users and hospitals. Secondly, the implications of developing new technology to support rehabilitation activities. In this section we describe these considerations in the context of our work with BIRT, as well as how the supervisory team and checkpoints were involved in reviewing the ethics of this work.

1.6.1 Supervisory Team and University of Bath Ethical Review

Given the clear connection of the research to a vulnerable population, the supervisory team and formal checkpoints on progress were fully involved with the ethical dimensions of the research. As described in Section 1.2, two doctoral supervisors had oversight of the ambition and direction of the research: Dr Leon Watts, an established HCI researcher who had previously worked in health contexts on video-mediated medical consultation, and Professor Nigel Harris, who at that time directed the Designability charity for assistive technology. Professor Harris had extensive experience of scoping and managing research and development projects intended to benefit highly vulnerable people, such as those with Alzheimer's Disease and children with severe cognitive and physical disabilities. In supervisory sessions, ethical concerns were a constant theme for reflection and fed into decision-making at every stage, going beyond the expected strategies for secure and anonymised data storage to potential side effects of empirical work on therapeutic practices. At the transfer viva in 2016, discussion of ethical oversight in relation to the systems the researcher and supervisory team intended to put in place were a central part of the examination (see Appendix A) and were judged to be appropriate.

From the time the research began in 2014 through to the final empirical study in 2017, the University of Bath had delegated ethical review to each of its constituent academic departments; there was no equivalent of a single, central 'Human Subjects Review' panel. The Department of Computer Science had implemented a two-stage process, under Dr Watts' guidance, when the necessity of department-level management of ethical review was first introduced in 2005. This involved a checklist addressing 13 distinct issues in determining the degree of risk and setting up mitigation in case any such risk was involved. Students were required to work with their supervisors to work through this process. In cases of uncertainty about any of the risks, the Departmental Research Ethics Officer should be consulted (a role Dr Watts had previously held). The strategy of deferring to the expertise and system of ethical checks used by the partner organisation, which we describe in the next subsections, was the primary risk mitigation strategy agreed upon.

The University of Bath has since established new procedures, allowing for cross-department collaboration in ethical review. Research with psychological or health-related implications must be referred either to the Psychology Research Ethics Commitee (PREC) or the Research Ethics Approval Committee for Health (REACH) respectively. Were the research as reported in this thesis to have been conducted at the time of writing, plans for the studies would have been submitted for consideration by these bodies as well.

1.6.2 Ethics of working with BIRT Services

Users of acquired brain injury rehabilitation services may, by ramification of their injury, have impairments that affect their understanding of language and information. This can be caused by aphasia – difficulty comprehending language – or by problems with memory and concentration (Henderson et al., 2019; Worthington and Alderman, 2017). In some cases, these impairments may be mild, or have been repaired through rehabilitation. In other cases, they may be more severe and present difficulties understanding or retaining information. Service users may also have a reduced awareness of their deficits and deny that they need support, or lack motivation for change through rehabilitation (Worthington and Alderman, 2017). Due to the issues presented by the effects of brain injuries, the responsibility for each person's rehabilitation rests with the clinical team, specifically the consultant neuropsychologist in charge of the service. The consultant is entrusted to make key decisions on behalf of the service user about a course of treatment, and to consider the purpose of activities and their implications for a service user's rehabilitation. During the course of our research, these consultants have acted as gatekeepers to the Brain Injury Rehabilitation Trust's hospitals, and to the people residing within them.

All of our research activities involving BIRT services have been carried out in close co-ordination with the responsible consultants. Access to these services has been strictly controlled and planned with the relevant consultant, who took the lead in setting the agenda of each visit and gradually exposed the HCI researchers to the brain injury domain. We describe our six visits to BIRT services in Section 3.5. Visits were initially to tour the facility over 2-3 hours, and evolved to include meeting other clinical professionals and eventually service users over several days. The researcher was supervised during the first five visits and was given free access to communal areas on the final visit. Each visit was interspersed with meetings with the consultant neuropsychologist, who would put happenings into context and decide what the researcher should do next.

During site visits, the accommodating consultant would sometimes make introductions to a service user encountered by chance. However, there were also service users who the consultant wanted the researcher to meet. Often these were people interested in gaming or technology, who the consultant wanted to tell about the research or to show us how our work may benefit them. The consultant's familiarity with each service user and their case history enabled them to make an informed decision about the value in the researcher meeting them.

This thesis presents two key research activities involving service users. In Chapter 5, we present the observation of a service user carrying out a community based assessment. As with the site visits, this activity was proposed by the responsible consultant neuropsychologist, who selected the service user to observe and arranged for the researcher to attend. Two members of the clinical team conducted the activity, which was routine and considered safe for the service user, and were present at all times to put the observation into context for the researcher. We describe this activity in more detail in Chapter 5.

In Chapter 8, we describe an activity where three service users used the virtual reality scenario (Virtuality Street) developed for this research. As before, the activity was proposed by the consultant, who spent time trying out Virtuality Street before deciding which service users should use it. The consultant was present and took time to explain to each service user what they would be doing, and was able to use their familiarity to tailor the explanation and to watch for any issues.

As with all activities taking place within BIRT services and with BIRT service users, our involvement here was authorised by the relevant consultant neuropsychologist, who deemed our activities to be appropriate.

1.6.3 Ethical Review Process

Ethical review was an important consideration from our first meeting with BIRT. One of the project leads (see Section 1.2) was the Research Fellow for the Disabilities Trust (DT; BIRT's parent organisation). The Research Fellow's role was to ensure that this project was compliant with research carried out in DT. This included advising on the ethical review processes required by research taking place within DT, and by extension within BIRT services and with service users.

All Engineering Doctorates supported by the Centre for Digital Entertainment at the University of Bath must involve the 'industrial partner' in developing and agreeing on project objectives and a proposed plan of work. For the research reported in this thesis, such a commitment was a welcome opportunity to ensure that all aspects of engagement with members of the BIRT community would adhere to organisational best practice, including clinical concerns for safety and safeguarding. The review process thus began with the project proposal which was jointly developed by DT's Research Fellow and the author of this thesis. This was absolutely necessary if the research was to be approved. For work with potential clinical impact, the relevant authority was the Disability Trust's Clinical Executive Board and so ethical oversight was at the core of the plan right from the beginning. The research proposal incorporated the following elements:

1. Complete formal literature review of technology available and clinical application.
2. Assemble demonstration systems for the technology.
3. Immersion in clinical environment.
4. Identify and select candidate technologies for further development.
5. Development of technology using user centred design methodology.
6. Proof of concept trials, based on a technology acceptance model. This may be a series of discrete studies examining different aspects of the technology, such as: user acceptability and performance, clinical utility and performance, practical application.
7. Further development of candidate technology for clinical evaluation, methodology, **ethics review**.
8. Clinical evaluation.
9. Write up.

Points 3, 5, 6 and 7 all demonstrate a commitment to ground the understanding of the researcher in meaningful clinical practice and to incorporate practice-lead lessons into the design process. In point 7, a formal ethics review was planned to coincide with the further development of a VR environment for clinical evaluation, which was planned to take place in the final year of the project. This formal review was planned to be via the long-established Disabilities Trust ethical review process. Activities prior to this, such as visiting services and performing proof of concept trials, were entirely consistent with routine BIRT practices. As such, the ethical considerations and permissions to work in individual BIRT services were under the direct authority and control of clinical consultants, as described in the previous subsection.

Before asking clinical practitioners and service users to engage with virtual reality technology, we prepared an application for the Disabilities Trust's Research Ethics Committee (Appendix B), including determining the nature of staff and service user involvement. The purpose of running virtual reality sessions with these groups was to gather feedback on the appeal and usability of the developed Virtuality Street system. This purpose and the procedures to be used were reviewed by DT's Research Fellow, who thereafter assisted with the application's redrafting with the mission of DT's Research Ethics Committee (REC) in mind.

The Disabilities Trust's process for determining whether a project needs REC review is informed by guidance published by the NHS Health Research Authority (Health Research Authority, 2016) and Twycross and Shorten (2014). The process uses criteria to determine whether a project proposes activity that corresponds to health or clinical research, or to a different category, that of service evaluation/public involvement. Although this may seem to be a minor point, it was a critical distinction for the work this thesis reports. A thesis is by its very nature concerned with carrying out and critically evaluating research. In this case, the thesis is positioned in the field of HCI research. Yet the remit of research activities in HCI is much broader in scope and intended outcome than in clinical and health research. Furthermore, effective HCI research depends on iterative refinement of design ideas with relevant user involvement to progressively validate and reformulate them. This is inconsistent with the concept of medical research, which depends on some version of formal clinical evaluation or trial of a fully formed intervention. This distinction meant that our research activities fell into the category of service evaluation/public involvement. The key issue was that the HCI research activities to be carried out would not be capable of proving outcomes for clinical practice until a research study evaluating the clinical utility of the technology was complete, which is outside the scope of this work. DT's Research Fellow determined that the aims of the work met the requirements of public involvement in research (INVOLVE, 2016), and that a formal DT REC review was not required.

Although the application form was not submitted to REC for review, each issue it raised directly helped to determine what might reasonably be done. So completing the form and revising it with input from DT's Research Fellow was an important step in considering the purpose and procedure of the proposed activities. The Research Fellow is highly experienced in designing investigations that fall both into and outside of the boundaries of clinical research. She drew on this expertise to assist in formulating the plan for engagement so that it was strictly contained within the scope of public involvement. The form was further useful as a briefing document for the consultant neuropsychologist of the BIRT service to be engaged with, to decide whether service users and staff should use the Virtuality Street environment.

As Virtuality Street evolves, thanks to public-involvement-level user input, the hope and expectation is that there will come a time when it is ready for clinical validation.

At that point, it will be necessary and welcome to engage with a full ethical DT REC review process. It would then be in a condition for clinical trials that go beyond the remit of public involvement.

1.7 Thesis Outline

This thesis is exploring how virtual reality can support rehabilitation activities and deliver meaningful benefits to people with acquired brain injuries. This section outlines how the structure of the thesis is conducive to this goal.

Chapter 1 – Introduction

In this chapter we have set out an overview of the research project and the multidisciplinary team involved. We have also established a scope with respect to the proportion of the brain injury population we are working with, the extent of the validation we are able to perform, and the purpose of VR development. We explained that our methodology has been to perform repeated input and validation so as to not introduce elements of rehabilitation so foreign to clinical professionals that they are unable to envision its practice or share in its vision.

Chapter 2 – Framework for Describing Effects of Acquired Brain Injury on Socio-cognitive and Functional Behaviour

Chapter 2 reviews the theoretical effects of acquired brain injuries on socio-cognitive and functional behaviour. We begin by seeking to understand what the cause of acquired brain injury are, and how the location and severity of the injury can predict a broad range of impairments. We then look at how injuries can impact upon the cognitive processes responsible for self-regulation and present a framework, a clinical model of executive functioning, to describe how brain injuries can affect independence by impairing socio-cognitive and functional behaviours. The outcome of this chapter is to understand the unique challenges arising from acquired brain injuries, particularly those related to a frequently affected part of the brain – the frontal lobes – and the implications that these have for rehabilitation.

Chapter 3 — Neurobehavioural Rehabilitation in Clinical Practice

This chapter begins with the broad goals of rehabilitation and a theoretically driven perspective of how neurobehavioural rehabilitation for socio-cognitive and functional behaviours take place. We then report on researcher-led visits to rehabilitation services run by the Brain Injury Rehabilitation Trust over a three year period, and describe how this practice implements a theoretical rehabilitation model. Rehabilitation activities are described in the context of a frequently discussed domain – community access – which is highlighted to us by clinical professionals. The outcome of this chapter is an understanding of the underlying principles of rehabilitation and the identification of practical constraints that might be facilitated by innovative and interactive technology.

Chapter 4 – Virtual Reality Prototype for Community Access

Chapter 4 provides an overview of virtual reality technology, its strengths and limitations, and some previous work in the rehabilitation domain. It then details the Virtual Bus Stop scenario in which a service user must get onto a bus and buy a ticket from a driver. We step through a storyboard of what a clinical session using virtual reality might look like, detailing the extent of dialogue and interaction between a service user and administering clinician. The development of the Virtual Bus Stop prototype demonstrates how the selected scenario might work in practice and tests some early ideas around how clinicians might control a VR environment and interact through a virtual proxy. Informal feedback is used to identify the strengths and limitations of the prototype.

This chapter kickstarts our iterative design methodology, in which we take ideas from clinical practice, incorporate them into a VR prototype, and seek feedback from domain experts. It showcases a productive working relationship between members of a multi-disciplinary team, and it contributes a validated storyboard and lessons to consider for further development.

Chapter 5 – Clinical Frameworks for Functional Assessment

Chapter 5 looks to understand the purpose of behavioural assessments for community-based activities, how this is performed in current clinical practice, and the strengths and limitations of this practice. The purpose is to further explore and understand the activities used in clinical practice for the rehabilitation of executive dysfunction, such that their salient properties can inform the design of a VR prototype that has meaningful use in a therapeutic programme. We start by outlining why behavioural assessment is important, using clinical input as guidance, before reporting on clinical frameworks that we were introduced to for behavioural assessment. Analysis of a test battery and an ethnographically inspired observation directly contribute to our understanding of the types of activities that someone with a brain injury might undertake. This includes the purpose of the specific therapeutic activity, the procedure and settings for conducting it, the insight it is designed to facilitate, and how it is assessed. All of these feed into the design of a virtual environment that could be integrated into a therapeutic programme and deliver meaningful benefits for service users and clinicians.

Chapter 6 – Developing Virtuality Street and the VS-MET

Chapter 5 details the design and development of a second prototype of a virtual reality environment, Virtuality Street, to build upon feedback and lessons from the Virtual Bus Stop in Chapter 4. We start by reporting the selection of a virtual reality system – a head-mounted display and its associated hardware and software. We find that the HTC Vive's room-scale tracking supports the more naturalistic interaction desired by users, and that as a desktop-based system allows for screen mirroring and data logging to support clinicians in their work.

The chapter goes on to describe the implementation of Virtuality Street, a VR environment centred around a street based in the UK. We detail the layout and contents of Virtuality Street, such as the buildings and objects within, and outline its limitations in scope. We also describe the use of animations and character dialogue to reflect earlier feedback from users and clinicians. The locomotion technique – how a person moves around the environment – is also considered with respect to literature and its implementation is described.

We then introduce the Virtuality Street – Multiple Errands Test (VS-MET), inspired by our observations of the Multiple Errands Test in Chapter 5. We show how the MET can be applied to its environment where the target environment here is the Virtuality Street platform. The selection of tasks and rules for the VS-MET is discussed and makes use of the available locations and objects in Virtuality Street.

The output of this chapter is a VR environment, Virtuality Street, to serve as an experimental platform for our research and future clinical use, and a tailored assessment, the VS-MET, to be administered in it.

Chapter 7 – Identifying Clinically Relevant Behaviours in the VS-MET

Chapter 6 contributes to the understanding of how virtual reality environments can be designed to mirror the properties of assessments for executive dysfunction. Having developed the VS-MET as a version of the MET adapted for a virtual environment, we seek to determine the extent to which components of executive functions are visible. The chapter reports on a lab study involving 11 neurotypical participants from the University of Bath.

Participants were given a task list to complete inside the VS-MET, with tasks adapted from those used in the MET. They were recorded navigating the environment with a combination of physical and controller-driven movement, and verbally interacting with a character within the environment. At the end of their attempt, participants were asked to watch themselves back to comment on their behaviour and thought processes.

This chapter demonstrates how observations can be made of people using the VS-MET and details the challenges that even neurotypical people can face when conducting tasks in this environment. By scoring behaviour we gather baseline data for neurotypical performance in the VS-MET, and we can generate a list of errors as examples of task failures, inefficiencies and rule breaks made by these participants. We can also make qualitative inferences about behaviour and participants' approach to tasks, demonstrating the VS-MET's capability to reveal observable and clinically relevant behaviours.

Chapter 8 – Engagement with Clinical End-Users

In this chapter we report on our final visit to a BIRT service, where we had the opportunity to work with three service users who were close to discharge and had been hand-picked by a consultant neuropsychologist to try Virtuality Street. We also gathered feedback from clinical professionals working in the service to get some preliminary feedback on Virtuality Street. We also describe feedback from clinical professionals at a separate and specialist brain injury hospital.

Chapter 9 – Conclusion

In this chapter we present an overview of this thesis' goals, state the contributions of this research, and outline a direction for future work.

Chapter 2

Framework for Describing Effects of Acquired Brain Injury on Socio-cognitive and Functional Behaviour

2.1 Introduction

The challenges of recovering from an acquired brain injury (ABI) can continue long after the trauma or condition responsible. The location and severity of a person's ABI may lead to physical, cognitive, emotional and behavioural impairments that have a profound impact on their daily lives, and thus has a direct impact on what such rehabilitation aims to address (Disabilities Trust, 2020; Headway, 2021a). ABIs have a unique and sometimes unpredictable effect on each person, calling for a flexible rehabilitative response to address the needs and abilities of the individual (Goll and Hawley, 1989, p.144).

ABIs frequently affect frontal lobe areas associated with both higher cognitive functioning and a variety of social competences. Taken together, these impairments of "executive function" impact on the group of cognitive processes responsible for monitoring and regulating behaviour (Sohlberg and Mateer, 2001). Termed executive dysfunction, this set of cognitive impairments presents a complex range of rehabilitation challenges. Seemingly basic everyday tasks, such as buying a bus ticket, require the coordination of many cognitive abilities and social awareness that are impacted by executive dysfunction. These impairments come together to limit a person's ability to deal with frustrations, temptations and distractions. Neurobehavioural symptoms characterised as challenging behaviours are common amongst those living with executive dysfunction and are associated with strong impulsivity manifesting as physical, emotional and social responses to situations. People so affected tend to be at risk of putting themselves in difficult social and physical situations and, as a result, require high levels of support and supervision.

In this chapter we present a review of the theoretical effects of acquired brain injuries on socio-cognitive and functional behaviour. We begin by seeking to understand what the cause of acquired brain injury are, and how the location and severity of the injury can predict a broad range of impairments. We then look at how injuries can impact upon the cognitive processes responsible for self-regulation and present a framework, a clinical model of executive functioning, to describe how brain injuries can affect independence by impairing socio-cognitive and functional behaviours. The outcome of this chapter is to understand the unique challenges arising from acquired brain injuries, particularly those related to a frequently affected part of the brain – the frontal lobes – and the implications that these have for rehabilitation.

2.2 Acquired Brain Injuries

This thesis is exploring how virtual reality can support rehabilitation activities and deliver meaningful benefits to people with acquired brain injuries. To effectively envision how technology could contribute to a rehabilitation programme, we should consider the background and purpose of rehabilitation activities, which aim towards re-establishing the independence of a person with brain injury. Sohlberg and Mateer (2001, p.25) note the importance of understanding the causes of cognitive impairments when considering the evaluation, treatment and goal setting of rehabilitation. The Brain Injury Rehabilitation Trust reflects this in its Outcome Report, showing that different types of brain injury lead to different rehabilitation needs (Disabilities Trust, 2020). In this section we look to understand the nature of the condition to be treated and its impact on a given individual, such as to ensure that our work is grounded in relevant brain injury theory.

Disabilities Trust (2021a) details the three main parts of the brain: the cerebrum, the cerebellum, and the brainstem. The cerebrum, which is divided into two hemispheres, controls much of human cognition and behaviour. It consists of four parts, shown in Figure 2-1:

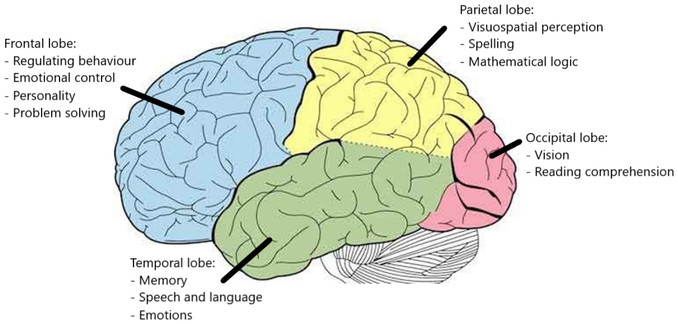

Figure 2-1: Lobes of the cerebellum annotated with functions. Adapted from Disabilities Trust (2021a).

- Frontal lobes (blue) – responsible for regulating behaviour, emotional control, personality and problem solving. The frontal lobes are the focus of this thesis and we discuss the effects of damage to it within this chapter.
- Parietal lobes (yellow) – visuospatial perception of the world around us, as well as spelling and mathematical logic.
- Temporal lobes (green) – memory, speech and language functions, and emotions.
- Occipital lobes (red) – Vision and reading comprehension.

Each hemisphere also has its own responsibilities in cognitive and behavioural functions. For example, the left side of the brain is believed to control motor and sensory functions in the right side of the body and speech and language. The right hemisphere controls the left side of the body and is more in tune with spatial perception and non-verbal memory (Disabilities Trust, 2021a).

The cerebellum, located at the back of the brain beneath the occipital lobes, controls balance, limb movements and motor coordination. The brainstem communicates with the rest of the body through the spinal cord, and assists in coordinating unconscious body functions such as breathing, urination and heart functions.

Any part of the brain can be damaged through a variety of injuries, and the severity and location of the injury has consequences for the type of impairment and subsequent rehabilitation.

2.2.1 Causes of Acquired Brain Injuries

An estimated 350,000 people are affected in the UK each year by an acquired brain injury (ABI), which is defined as any injury to the brain that has occurred after birth (Headway, 2021c). ABIs can occur at any time and through many causes, with the most common being trauma to the head. Strokes, which are disruptions of blood flow to the brain leading to cell damage, are a leading cause of disability in the UK and are similarly common as types of ABIs (Headway, 2021d; Public Health England, 2018; Disabilities Trust, 2020). Other causes, ranging from brain tumours to carbon monoxide poisoning, are less common but still account for nearly 20% of ABIs sustained in the UK each year.

The Headway charity has published key statistics over a 12 year period (from 2005 to 2017) about acquired brain injuries as part of its mission to provide support, information and understanding around ABIs (Headway, 2021d). This section draws upon these statistics.

Traumatic Brain Injuries

Traumatic brain injuries (TBIs), also known as a head injury, are the most common cause of brain injury in the UK, with over 150,000 admissions in 2016-7. A TBI is caused by any externally originating trauma to the head, such as from a car crash, fall, or assault, and the injury consists of this initial trauma plus the subsequent arising complications. Headway (2021g) describes a TBI as a “chain of events” consisting of three cascading injuries.

The first is the initial injury which can be categorised depending on the type of trauma sustained. A closed head injury may show little superficial evidence of trauma to the skull, but it has caused the brain to move or twist in such a way as to inflict damage. For instance, a closed head injury is a common occurrence in car crashes, when a rapid deceleration has led the brain to impact the front of the skull. Such an incident causes blunt trauma to the frontal lobes (see Section 2.3) but can have a rippling or diffuse effect throughout the brain and cause widespread damage. An open head injury is identifiable by penetration of the skull, exposing the brain to damage. The nature of this type of trauma, where an object (e.g. bullet, glass shard) may have penetrated the brain, typically means that damage is quite localised. A crushing head trauma may occur from the head being caught between two objects, and it can cause twisting of the brainstem more than to the brain itself. These types of trauma can also happen in parallel; we might imagine a car collision in which the brain impacts the front of the skull through deceleration and is also penetrated by flying glass.

The second injury can happen within minutes or hours of the first, where the brain does not receive an adequate oxygen supply due to blocked airways and loss of blood through other wounds. We shall briefly detail the effects of oxygen starvation on the brain shortly, but this secondary injury can exacerbate the damage caused by the initial trauma. In the case of an open head injury, infection is also a possibility that could lead to further impairment (Rosenthal and Ricker, 2002, p.52).

Lastly, the third cascading injury could occur weeks after the trauma as a consequence of bleeding or bruising. The brain may swell as blood leaks out, causing it to press up against the walls of the skull and both leading to tissue damage and restricting blood circulation. Blood clots can also form in or around the brain, creating pressure or resulting in oxygen starvation.

These second and third injuries mean that observations and treatment can be required for days or weeks after the traumatic event, as risks such as blood clots or bleeds should be monitored for. Parts of the brain responsible for alertness and consciousness may be affected by either direct or diffuse trauma by any of these cascading injuries, leading to a lack of consciousness or comas. In addition, the nature of a traumatic brain injury means that a person may suffer other physical injuries that require medical treatment and recovery.

The effects of TBIs are predominantly based on the location of the injury. For instance, if the frontal lobes were to impact the front of the skull, a person might experience impairments to their planning, emotions and behaviour (see Section 2.3). If one side of the brain was impacted, there might be weakness in the opposite side of the body. Furthermore, damage to the left side could result in speech impairment, or spatial perception difficulties could arise from the right side. However, diffuse effects, along with second or third injuries, have the potential to damage parts of the brain far from where the initial injury took place.

Vestibular disorders can also manifest after a traumatic brain injury, disrupting communication between regions of the body and leading to dizziness or balancing issues.

Traumatic brain injuries can therefore result in a mix of impairments that are caused by widespread damage to the brain, not just the initial localised impact, and are further compounded by the physical injuries sustained in the traumatic event. TBIs then are an unpredictable form of brain injury that can take weeks or months to recover from the acute physical trauma. Rehabilitation for the brain injury may therefore be delayed until the individual is fit for therapy, or may have to cope with long-term physical impairments that could hinder the rehabilitation process.

Strokes

Strokes are a leading cause of death and disability in the UK, with an estimated one in six people expected to suffer a stroke in their lifetime (Public Health England, 2018). Statistics vary, with Headway (2021d) reporting that around 130,000 people are admitted to hospital with an ABI caused by stroke each year, whilst the Stroke Association (2021) reports this figure as lower at 100,000. A stroke occurs when blood flow to the brain is disrupted and falls into one of two types: ischaemic and haemorrhagic.

A haemorrhagic stroke occurs when a blood vessel bursts and leaks blood into the surrounding brain tissue. This bleeding can lead to swelling, causing the brain to press against the insides of the skull and cause damage. There is also localised damage around the bleeding, the effects of which vary with the location and size of the haemorrhage. Ischemic strokes are more common, accounting for 85% of strokes (Sohlberg and Mateer, 2001, p.40; Stroke Association, 2019). In this type of stroke, a blood flow disruption leads to an infarction – an area of the brain deprived of blood leading to oxygen starvation. Even a small infarction can have lasting and significant behavioural and cognitive impairments (Allen, 1984; Sohlberg and Mateer, 2001, p.40). As with haemorrhagic strokes, the nature of impairments can vary depending on the location and size of the infarction, and the attribute of the affected person. These factors are a greater predictor of stroke outcome than the type of stroke (Sohlberg and Mateer, 2001, p.40).

Sohlberg and Mateer (2001, pp.39-43) describe consequences of strokes as found in three key arteries in each side of the brain. Strokes in the middle cerebral artery, located around the centre of the brain between the anterior and parietal lobe, are most common. They generally result in motor and tactile impairments, as well as impairments to verbal learning, speech production and comprehension (left side) or impairments to nonverbal learning, visuospatial perception, communication, attention, and awareness of the impairments themselves (right side). Although Sohlberg and Mateer describe impairments to memory and the thalamus when strokes occur in the posterior cerebral artery, they also note these to be rare. Strokes in the anterior communicating artery typically cause amnesia, confabulation (errors in memory), and executive dysfunction (see Section 2.3). This artery runs through the basal forebrain and the frontal lobes, meaning it is commonly affected by frontal TBIs in addition to strokes.

Generally, strokes affecting the left side of the brain typically impact motor and sensory functions in the right side of the body and can often lead to speech and language problems, particularly in left-dominant people. Conversely, right brain strokes affect the left side of the body and introduce difficulties with spatial perception or impulsive behaviour. Other complications of a stroke may include difficulty swallowing, fatigue, visual impairments, psychological disorders, or vestibular disorders (BUPA, 2019).

Strokes have a wide range of potential physiological, behavioural and cognitive consequences, and even a relatively small or localised stroke can have a severe impact on many functions of the body. Any rehabilitation programme must consider the full range of impacts and be tailored to an individual if cognitive impairments are to be approached effectively.

Demographics

An acquired brain injury can affect anyone at some point in their life and are not limited to specific demographics of people. Headway (2021d) provides statistics on the number of people in each country within the UK admitted to hospital with ABIs[1]. These statistics show that people of all ages were admitted, with children under 4 and adults over 65 being most commonly admitted in 2016-7. However, some groups of people are more prone to certain types of injury than others.

Traumatic brain injuries were the most common cause of ABI in 2016-7, making up over 150,000 cases. At a broad overview, children under 4 and adults over 85 were the most commonly affected by TBI, which is primarily due to falls (Sohlberg and Mateer, 2001). A larger number of males were admitted for TBI between 15-29, whereas there were triple the amount of TBI occurrences in females over 85 than in any other female age group. This mirrors the widely reported trend that the youngest and oldest members of society, along with young males in their teens and twenties, are the groups most at risk of TBI (Rosenthal and Ricker, 2002, p.50; Disabilities Trust, 2021a). Road accidents are responsible for many TBIs sustained by young adults, and injuries in urbanised areas are frequently due to assault. Alcohol also plays a frequent role in these incidents (Sohlberg and Mateer, 2001, pp.26-27). Although men are 1.6 times more likely to

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[1] Headway provides source data sets for each geographical region of the UK at https://www.headway.org.uk/about-brain-injury/further-information/statistics/statistics-resources/. This data has been obtained from the Hospital Episode Statistics database for England and its equivalents elsewhere in the UK. ABI admission data was obtained using International Classification of Disease Version 10 (ICD-10) codes, which describe diagnoses for admission data, as detailed in https://www.headway.org.uk/media/7866/brain-injury-statistics-methodology-injury-categories-and-further-notes-2018.pdf. Headway provides these statistics up to 2016-17.

experience TBI than women, female TBI admissions rose 24% between 2005 and 2015 (Headway, 2015).

Strokes accounted for around 130,000 hospital admissions in Headway's (2021d) statistics, the second most frequent cause. The statistics show that the number of people admitted with stroke increased with age, however there is a shift in pattern between men and women. More males suffered strokes between 60-84, with only a slight increase in the over 85s. The number of females admitted with stroke caught up to men in the 80-84 bracket, but was double any other bracket (male or female) for the over 85s.

Lifestyle choices can also contribute to the risk of some brain injuries. For example, smoking and alcohol abuse can increase the risk of stroke, as can certain medical conditions such as diabetes or high blood pressure (Headway, 2021e). These factors are expected to introduce their own complications for post-acute care and rehabilitation, as conditions such as blood pressure need to be managed, and handling alcohol or tobacco dependency may need to be considered and intervened where necessary.

Rehabilitation must then cope with a wide variety of conditions, life circumstances and experiences. For the context of our work, this includes people of a broad demographic with inevitably diverse exposure to technology, in addition to the complications associated with the injury itself.

Summary

In this section we have looked at the definition of acquired brain injuries and examined some of the types of ABIs that might occur. Although each person is unique and thus is uniquely affected by their ABI, an understanding of the different types of ABIs can help rehabilitation professionals to predict and appreciate patterns of impairments that may arise from the injury. The selection and implementation of rehabilitation strategies should be informed by a sound theoretical model if it is to be properly tailored to the impairments that person is affected by (Sohlberg and Mateer, 2001, p.56). For instance, the Brain Injury Rehabilitation Trust describes how individuals' needs are likely to change depending on the cause of injury. Communication and mobility impairments are more often found in people who have suffered a stroke, whilst impairments to memory and practical tasks are more common in TBI survivors (Disabilities Trust, 2018)). We will look at these rehabilitation needs later in this chapter.

The demographics and cause of injuries can also indicate other factors, such as alcohol abuse or physical disability, that may be of important consideration in rehabilitation.

It is important to understand how ABIs impact upon the cognitive and behavioural functions of an individual. In the next section we will focus on the effects of injuries to the frontal lobe, a common site of damage in acquired brain injuries.

2.3 Executive Functions

In Section 2.2 we looked at the effect that different types of acquired brain injuries can have, both with respect to physical consequences and to neuropsychological and physiological impairments when considering different parts of the brain. For example, traumatic brain injuries can have a diffuse effect on multiple parts of the brain far from the site of the trauma. Alternatively, strokes in the centre of the brain near the parietal lobe can impact speech and language or mobility.

A common area of the brain that is damaged through an ABI is the frontal lobe. Its position at the front of each hemisphere make it vulnerable to injury from a variety of sources. Most commonly, the rapid deceleration involved in road collisions causes the brain to rock forward and for the frontal lobes to impact ridges along the front of the skull. Falls, violent acts, or sport activities can all lead to blunt trauma impacting the forehead and frontal lobes. Strokes or aneurysms in blood vessels crucial to the frontal lobes, such as the anterior communicating artery, can cause lasting damage to these areas. Substance abuse and developmental anomalies can also cause problems in the frontal lobes, which may not fully mature until adulthood (Johnson et al., 2009). ABIs frequently affect these frontal lobe areas, which are associated with both higher cognitive functioning and a variety of social competences; this has important consequences for rehabilitation.

When an injury occurs to the frontal lobes, it can impair the cognitive processes involved in the self-regulation and monitoring of behaviour and goal management. These processes are collectively known under the umbrella term “executive functions”. Executive functions can be defined as the “cognitive abilities involves in the initiation, planning, sequencing, organization, and regulation of behaviour” (Sohlberg and Mateer, 2001, p.111; Stuss and Benson, 1986). When these cognitive processes are impaired, this “executive dysfunction” can impede behaviours. The role of executive functions and the associated dysfunction is clear when considering the performance of some everyday life skills, such as the ability to talk about a topic, to brush one’s teeth, or to vacuum a carpet. The individual motor or verbal skills, or underlying knowledge, are independent to executive functions and may be intact. The executive functions are invoked when the regulation and management of these behaviours are required (e.g. stay on topic, stop brushing teeth, start vacuuming the carpet). When executive functions are impaired, even seemingly simple everyday tasks such as these can become difficult.

Cognitive theories have been developed to model how the executive functions are utilised in activities. An important clinical model used for people with executive dysfunction is Norman and Shallice's (1980) Supervisory Attentional System (SAS). They argue that the SAS is invoked when facing a non-routine or novel situation using markers. Here, markers are a theoretical construct used to signal the brain that a shift in behaviour is necessary. Specifically, that executive control should take over from a current behaviour and conduct some non-routine task. We might describe this as an autopilot process for the brain; engage the autopilot to do a routine task but switch out of it when needing to handle an unexpected event.

When receiving a goal to work towards, the SAS invokes six distinct processes. For example, if given the goal to find a post office in the high street:

- Goal articulation – "I am going to find the post office on the high street."
- Provisional plan formulation – "I will walk down the street until I find the post office."
- Marker creation – "If I see the post office, I will stop walking."
- Marker triggering – "I can see the post office, I need to stop walking now."
- Periodic evaluation – "I have not yet found the post office, so I should continue walking."
- Plan modification – "I have been looking for a while, I could ask someone for directions."

Norman and Shallice further argue a distinction between routine or overlearned tasks, and non-routine tasks. The executive functions are employed only when these non-routine or novel tasks are present.

Many theories have been proposed to categorise the brain's regulation of behaviour into discrete components (Luria et al., 1966; Stuss and Benson, 1986; Keil and Kaszniak, 2002). Luria et al.'s (1966) model first acknowledged impairments in task planning, where a person could not formulate a plan, constrain potential strategies, or prevent impulsive behaviour. Luria proposed four components of executive functioning, described by Purdy (2016) as:

- Anticipation – Setting realistic expectations and anticipating the consequences of behaviour.
- Planning – Generating a plan to solve a problem or complete a task.
- Execution – Following through with the plan and being flexible to deal with interruptions.
- Self-monitoring – Recognising when an error occurs and assessing own progress at adhering to the plan.

Luria's model of executive functioning has formed the basis for much subsequent work, and numerous theories that categorise behaviour into components have been proposed.

Through our work with clinical neuropsychologists from the Brain Injury Rehabilitation Trust (see Chapter 3), our approach has been guided primarily by a clinical model of executive functioning by Sohlberg and Mateer (2001) that is frequently used in current clinical practice. It is based on a model of executive functions proposed by Mateer (1999) that identifies components with high clinical relevance and considers the handling of non-routine and novel tasks afforded by Norman and Shallice's Supervisory Attentional System.

Table 2.1 shows the six components of executive functioning, as presented in Sohlberg and Mateer's (2001) clinical model of executive functions. They are initiation and drive, response inhibition, task persistence, organisation and planning, generative thinking, and awareness. These components cover a range of cognitive and behavioural processes, and a person with a brain injury to the frontal lobes might experience impairment in just one, in multiple, or across all these components. Considering executive dysfunction as impairments to any one of more of these theoretically valid components enables clinical professionals to more precisely describe what deficiencies might exist following an acquired brain injury.

Amongst these, awareness has special significance for rehabilitation because it can seriously inhibit a person's willingness to participate in rehabilitation. Impaired self-awareness can cause a person to believe that they are behaving without any problems, or to not have a grasp of the extent of their deficits (Worthington and Alderman, 2017). Clinically this is often referred to as *insight*. A lack of insight can result in a person being unwilling to engage in rehabilitation activities because they do not think there is an issue to correct. Facilitating insight as a motivator for engagement and change is a key factor in rehabilitation Worthington and Alderman (2017).

Component	**Executive function**
Initiation and drive	Starting behaviour
Response inhibition	Stopping behaviour
Task persistence	Maintaining behaviour
Organisation	Sequencing and timing behaviour
Generative thinking	Creativity, fluency, problem solving skills
Awareness	Self-evaluation and insight

Table 2.1: Clinical model of executive functions, adapted from Sohlberg and Mateer (2001, p.237)

Sohlberg and Mateer's clinical model of executive functioning enables clinical professionals to describe a given person's behaviour as the sum of impairments to different conceptual components of EF. This informs a rehabilitation strategy that can be tailored towards addressing impairments to these components. In the next section we shall examine how such impairments to the executive functions translate into consequences for behaviour and present a clinical need for rehabilitative intervention.

2.4 Neurobehavioural disability following acquired brain injury

We have looked at how acquired brain injuries can occur, and how the attributes of an injury can predict the types of physical and cognitive impairments that may arise. Frontal lobe injuries are frequently encountered in clinical practice, which can result in impairments to the executive functions; an umbrella term for the cognitive processes that regulate and monitor behaviour. Acquired brain injuries, and executive dysfunction in particular, can have implications for a person's behaviour. Wood (1987) terms this dysexecutive impairment to self-regulation "neurobehavioural disability". Worthington et al. (2017) define this as:

> *Patterns of maladaptive behaviour characterised by impulsivity; inappropriate social or sexual behaviour; lack of tact and discretion during interpersonal activities; diminished self or social awareness; an egocentric attitude lacking in warmth and empathy towards others; labile mood with shallow irritability that can escalate into impulsive aggression; poor attention control resulting in an inability to maintain goal directed behaviour; a lack of ability*

> *to spontaneously initiate purposeful behaviour; and fatigue, often associated with a lack of drive and motivation." (Worthington et al., 2017, p.4).*

The different components of this definition fall into two categories of behavioural impairment: socio-cognitive (how the person engages in social interactions) and functional (the ability to plan and perform tasks). In this subsection we describe how neurobehavioural disability arising from executive dysfunction affects social interactions and functional tasks.

2.4.1 Socio-cognitive behavioural impairment

Changes in social behaviour and personality are frequent after an acquired brain injury. They can be left with deficits to socio-cognition, impeding their ability to navigate social situations. They might have difficulties interacting in conversation, predicting the flow of a dialogue, or recognising and responding to emotions conveyed by other people (Williams and Wood, 2017).

In their clinical model of executive functions, Sohlberg and Mateer (2001) demonstrate how social interactions are adversely affected by impairments to the six components of executive functioning (Table 2.2). Any one or more of these components can be impaired to hinder a successful social interaction. For example, during our work with the Brain Injury Rehabilitation Trust we encountered "Adam", a 46-year old man recovering from TBI. Adam came across as apathetic and uninterested in conversation, only responding rather than initiating conversation, and only giving short answers. Clinical professionals working with Adam identified impairments to his initiation, persistence, generative thinking and awareness as contributing factors to this behaviour.

People who have survived an acquired brain injury can also suffer from having an outward appearance of their pre-injury self, whilst having undergone significant personality and social behavioural shifts. A BBC documentary of the Brain Injury Rehabilitation Trust introduces Amanda, who had suffered a TBI from falling off a horse and was attempting to return to her family. Amanda's family describes her as having a "short fuse" and having "lost her squidgy bit". Amanda's son felt that she was an "intruder", but that she "was in there somewhere but couldn't get out" (BBC, 2016). Another person featured on the BBC documentary, Earl, is described by his mother after a car accident: "The only thing that's the same about Earl is his looks... He's a different person but he's still my son" (BBC, 2016).

Headway features the history of Alex, whose brain injury had been caused by tumours (Headway, 2013). Alex describes how his injury has affected his social skills, noting

Component	**Executive dysfunction applied to communication**
Initiation and drive	Does not initiate conversation; exhibits flat affect with limited expression
Response inhibition	Makes inappropriate comments; does not wait for turn in conversation
Task persistence	Loses interest in conversation; cannot maintain topic
Organisation	Poor verbal organisation; jumps from topic to topic; seems to talk "around the subject" and not get to the main idea
Generative thinking	Unable to generate conversation; seems to have little to say; has difficulty responding to open-ended questions
Awareness	Seemingly unaware of communication deficits; does not seem to notice if others are not interested in topic

Table 2.2: Application of clinical model of executive functions to communication disorder. Adapted from Sohlberg and Mateer (2001, p.237).

that he "can be abrupt and rude". He goes on to say that his personality changed dramatically, calling it "almost a Doctor Jekyll and Mister Hyde scenario", and that this has impacted on his relationships with his family. His short term memory has also greatly diminished and has consequences for his social interactions; he mentions that he cannot remember the interviewer's name but was able to recall events from forty years earlier. His outward appearance is again highlighted:

> *"My outward appearance would indicate that there is nothing wrong with me. However, I get a number of suspicious looks from bus drivers: 'How have you wangled [a disabled bus pass]?'" (Headway, 2013).*

Alex draws a contrast between brain injury as a hidden disability and people with outward physical disabilities.

> *"If you see somebody with a broken leg: 'He's got a broken leg'. He will recover, and there are visible signs that he will recover. Not with me." (Headway, 2013).*

This comparison exemplifies how people with personality and behavioural changes can be or feel misunderstood. Rudeness or apathy can be perceived as a character trait rather than a consequence of brain injury. Although some causes of brain injury can come with physical signs of disability, such as a broken leg in a car accident, the brain injury itself can have a profound impact on someone's social behaviour without any visible indications to others that a neurobehavioural disability exists.

The mannerisms of someone with socio-cognitive impairments (e.g. being short-tempered) can be met with rudeness from people who do not recognise the neurobehavioural disability. Speech and language impairments such as slurring, or mobility impairments

Component	**Executive dysfunction applied to grocery shopping**
Initiation and drive	Does not initiate going to grocery store even when refrigerator is empty
Response inhibition	Impulsive shopping; buys unnecessary items that look appealing during the shopping excursion
Task persistence	Does not get all the items on the list
Organisation	Does not make a grocery list; does not use aisle headings to shop in an organised manner; inefficient use of time when gathering grocers.
Generative thinking	If desired item is not available, cannot generate appropriate substitute
Awareness	Is not aware that getting groceries is an area of concern

Table 2.3: Application of clinical model of executive functions to grocery shopping. Adapted from Sohlberg and Mateer (2001, p.237).

such as balance deficits, can also contribute to misconceptions about behaviour. A person with executive dysfunction might readily be misperceived as someone who is drunk or having taken drugs, raising suspicion against them.

In his interview with Headway (2013), Alex recognises that can be rude and abrupt. Not all people with socio-cognitive behavioural impairments have this awareness. As highlighted previously, insight plays an important role in the recognition of deficits and motivation for change. During our work with BIRT, clinical professionals described an outgoing young man who had suffered a TBI through a fall, leaving him with social impairments. When his friends visited him, the young man was rude to them and insulted them. Staff broached the subject with him, but he was convinced that his behaviour was friendly and as it had been pre-injury, and he refused to engage in social rehabilitation.

People recovering from ABIs may struggle to exhibit the patience, persistence and politeness required in everyday social encounters. They are further handicapped by atypical mannerisms that tend to colour the attitude of members of the public towards them. Consequently, they may have to deal with suspicion and rudeness much more commonly than a neurotypical person, and they may lack the insight to understand why. Rehabilitation thus includes the handling of social interactions as a key requisite for the goal of independent living.

2.4.2 Functional behavioural impairment

People with executive dysfunction can have difficulties performing both everyday and non-routine tasks. Table 2.3 shows how Sohlberg and Mateer's clinical model of executive functions applies to the everyday activity of shopping for groceries.

The application presented by Sohlberg and Mateer highlights the challenges that might be faced by someone with executive dysfunction in a common everyday activity: grocery shopping. As shown in the example, this activity consists of many different tasks, such as making a grocery list, navigating aisles, or managing time. Many everyday living skills required for independence involve these complex sequences of behaviours and competing demands and responsibilities. These may seem simple to a neurotypical person, but to someone with dysexecutive symptoms these behaviours can be difficult to coordinate and string together.

O'Reilly et al. (2007, pp.255-257) present task analyses that breaks down three everyday life skills into their component tasks. These skills are brushing teeth, making a sandwich and supermarket shopping. Although, for example, brushing teeth is a seemingly simply activity that many of us do with ease every day, the analysis breaks this activity down into 14 discrete tasks. These include wetting the toothbrush, applying toothpaste, and rinsing the month. Executive impairments could impede a person's ability to perform any one or more of these tasks:

- Initiation and drive – At a general level, the motivation to brush teeth may not be there. The person may pick up the toothpaste but then not initiate the task of applying it to the toothbrush.
- Response inhibition – Coming to the end of a task might be difficult. For example, they might start brushing but not stop.
- Task persistence – The person may start the tasks but give up or become disinterested halfway through. They may brush one part of the mouth and then give up.
- Organisation – Unscrewing the toothpaste before picking up and wetting the toothbrush. Not having toothpaste might be a longer-term planning issue.
- Generative thinking – If the toothpaste has run out, they might not think to open a new packet. If the water is not working in the sink, not searching for another tap.
- Awareness – They may not be aware that brushing teeth is an important hygiene consideration. With respect to insight, the person might brush their teeth but not monitor their progress, such as not re-brushing areas of the mouth that are visibly unclean.

Any single one of the sub-tasks that form up an activity could hinder efforts to complete it. In making a sandwich, this could be failure to butter the bread. In supermarket shopping, it could be not picking up a basket.

Of note, the underlying cognitive and motor abilities required to perform these tasks are usually intact (e.g. the ability to hold a knife and butter bread). Executive dysfunction is an impairment to the regulation and coordination of intact behaviours. People in independent living situations are generally capable of piecing together the relevant behaviours required to plan and complete tasks towards a specific goal. Functional rehabilitation is about assessing how impairments prevent the successful application of behaviours in tasks, teaching strategies to overcome these impairments, and facilitating a learning environment where these task behaviours can be practiced.

As before, insight remains a crucial barrier to the successful rehabilitation of functional behaviours. A person with impaired insight may fail on specific tasks; in the teeth brushing example, a lack of insight could lead someone to think they've brushed all areas of the mouth well when they have not. However, it also prevents a constructive therapeutic dialogue where the person and therapist identify weaknesses to address. Lack of insight may lead that person to claim they are performing the functional activity well and that they do not need practice or rehabilitation. Discovering how to foster this insight is a key rehabilitation concern.

Deficits in inhibition and persistence can also come together to hinder a person's ability to deal with temptations, distractions and frustrations. Being able to block out stimuli is an essential part of productive behaviour, where we can go about a daily routine without being distracted. Inhibiting our responses to frustrations is also important in people functioning as polite and respectful members of the community, but may be difficult for someone with neurobehavioural symptoms. Temptations can likewise challenge our ability to stick to a plan; even neurotypical people may struggle to pass up sugary foods when trying to follow a diet, and this can be even harder for people struggling with impulsivity deficits. When we consider the role of alcohol or drugs in some brain injuries – TBI and stroke can both be caused by these – there is a risk of addiction as a consequence to disinhibition. Indeed, gambling addiction is recognised as a high risk consequence of frontal brain injuries due to these impairments of inhibition and impulsive behaviour (Headway, 2021f).

Many functional activities are made up of complex sequences of tasks that may have competing demands or require linear execution. Dysexecutive impairments can present issues performing any one of these tasks and impede efforts to complete the activity. The activity might also be disrupted through temptations, frustrations or distractions. Furthermore, a lack of insight can leave a dysexecutive person convinced they have performed the task well, and they can be unwilling to engage in practice activities. An ideal rehabilitation strategy should be to enable the assessment and practice of tasks in realistic settings in order to identify weaknesses and train compensatory skills.

2.4.3 Challenging Behaviour

A common consequence of executive dysfunction and neurobehavioural disability is challenging behaviour. This can typically be described as physical or verbal aggression against others or self, shouting, refusing to move, or refusing to carry out a task (McClean and Grey, 2007). Inappropriate sexual behaviour, which includes verbal comments, personal contact, exposure and touching others, is also widely acknowledged as challenging behaviour (Knight et al., 2008). With respect to the clinical model of executive functions introduced in Section 2.3, we might consider these symptoms of impaired inhibition and awareness.

Defining what constitutes challenging behaviour is difficult, with clinicians disagreeing on less overt behaviours than aggression and sexual behaviour (Alderman, 2017). Instead, challenging behaviour is often defined by its impact and consequences, rather than by its topography. Behaviours can be considered challenging if they provide an obstacle to active social involvement, successful community re-integration, return to occupation, to independent living, or to caregiving (McClean and Grey, 2007). McClean and Grey report the case of a 22 year old woman, “Sarah”, whose physical and verbal aggression against herself and caregivers – including injuring care staff – was classed as challenging behaviour for its impact on herself and those around her.

Challenging behaviour, as a term to describe impacts and consequences, can also describe the inability for a person to look after themselves. In the previous subsection we described meeting “Adam” during our work with the Brain Injury Rehabilitation Trust. Rather than aggression or inappropriate behaviour towards others, Adam’s challenging behaviour was a lack of activity and drive to perform chores, instead preferring to watch television. This behaviour was deemed challenging due to concerns that he would not be proactive in looking after himself. These were impairments with task initiation and drive, awareness and planning. We discuss Adam to a greater degree in Chapter 5.

In their severest instances, people with challenging behaviour may be detained under the Mental Health Act and have an enforced stay in a secure rehabilitation centre. Such services will be looked at in Chapter 3 when we discuss neurobehavioural rehabilitation in clinical practice.

A further descriptor of challenging behaviour is that it may be unpredictable (Bromley and Emerson, 1995). People with challenging behaviour may behave well in some settings or with particular people, but get aggressive or inappropriate when faced with certain situations. This is of concern for people who spend substantial time in rehabilitation units. They might behave well for weeks or months and then relapse once clinical support is removed or when confronted with a situation that had not been encountered during care.

2.5 Conclusion

This chapter has sought to establish the domain within which we are working, to understand the unique challenges presented by acquired brain injuries to the socio-cognitive and functional behaviours of people so affected.

When brain injury affects the frontal lobes, it can impair the cognitive processes responsible for regulating and monitoring behaviour. Even seemingly simple everyday life skills, such as shopping, brushing teeth or socialising, can be difficult for someone experiencing dysexecutive symptoms. They may experience difficulties starting, stopping or continuing with functional tasks, planning out or thinking creatively about activities, or having insight into their own limitations and needs for intervention. Executive dysfunction can lead to troubled social interactions, where impairment might be mistaken for rudeness or apathy.

There are therefore wide-ranging implications on socio-cognitive and functional abilities that have relevance to everyday life skills both at home and out in the community. These are further compounded by challenging behaviours which can be unpredictable and vary between residential and community settings. Consequently, the ability to safely live at home and engage with the community is compromised, where the skills for independent living are impaired. People with neurobehavioural disability arising from dysexecutive symptoms are therefore not safe to life independently and require rehabilitation to restore these independent living skills.

Rehabilitation should seek to support the reacquisition of these everyday living skills required by independent living, provide an appropriate setting to do this, and consider the unique experiences, life circumstances and conditions of a person in a rehabilitation strategy. Having referred obliquely to “rehabilitation” in this chapter, in Chapter 3 we will look at the theory and practice behind rehabilitation.

Chapter 3

Neurobehavioural Rehabilitation in Clinical Practice

3.1 Introduction

The research presented in this thesis is exploring how virtual reality technologies could be used to support rehabilitation activities and deliver meaningful benefits to people involved with acquired brain injury rehabilitation. We have so far developed a fundamental understanding of the types of challenges that might be imposed on someone as a result of executive dysfunction. There may be a wide range of socio-cognitive and functional challenges arising from neurobehavioural symptoms, that may be further impeded by challenging behaviour.

In Chapter 2 we considered the impacts of these deficits on everyday life activities. Socio-cognitive and functional skills are essential to many activities involved in independent living, and even simple functional activities such as making a sandwich or going shopping can be hampered by executive disruption to a single sub-task (O'Reilly et al., 2007, pp.255-57; Sohlberg and Mateer, 2001). Social interactions can also be difficult; a person may struggle to navigate conversations, read and respond to emotions, or manage attention. Insight may be lacking to understand when they are being rude or inappropriate, and they may struggle to exhibit the patience, persistence and politeness required in day-to-day social activities. They may also have to deal with suspicion and rudeness from members of the community in response to their mannerisms.

These impairments of behaviour relate to the everyday life skills that people require for safe and independent living, and a common consequence of brain injury is that independent living is no longer possible. Rehabilitation should seek to support the reacquisition of these independent living skills, provide a suitable setting for rehabilitation, and consider the nuances of a person's behavioural disability.

In this chapter we present a theoretical understanding of rehabilitation activities in this domain, and observations of how this theory translates into practice through our research collaboration with the Brain Injury Rehabilitation Trust. These contribute towards our first research objective:

1. To explore the types of activities conducted in clinical practice for the rehabilitation of executive dysfunction, including their purpose, strengths and limitations.

The post-acute rehabilitation of ABIs seeks to restore levels of social independence in people with challenging behaviour, and to support the learning of strategies to compensate for impairments (Worthington et al., 2017; Disabilities Trust, 2020). The rehabilitation of executive dysfunction, a core feature of neurobehavioural disability, is seen as a key predictor of successful reintegration into the community (Sohlberg and Mateer, 2001; Wood and Bigler, 2017). Clinical professionals working to rehabilitate neurobehavioural disability employ a structured environment with systematic recordings and behavioural management interventions (Worthington et al., 2017; Alderman and Wood, 2013).

This chapter begins with the broad goals of rehabilitation and a theoretically driven perspective of how neurobehavioural rehabilitation for socio-cognitive and functional behaviours take place. We then report on researcher-led visits to rehabilitation services run by the Brain Injury Rehabilitation Trust over a three year period, and describe how this practice implements a theoretical rehabilitation model. Rehabilitation activities are described in the context of a frequently discussed domain – community access – which is highlighted to us by clinical professionals. The outcome of this chapter is an understanding of the underlying principles of rehabilitation and the identification of practical constraints that might be facilitated by innovative and interactive technology.

3.2 Rehabilitation

Post-acute rehabilitation of an acquired brain injury can be a lengthy process that lasts months or years past the initial injury. For many, a comprehensive rehabilitation programme will be required to return them to activities of daily living. Defining the purpose of rehabilitation, Nocon and Baldwin (1998) state that "The primary objective of rehabilitation involves restoration (to the maximum degree possible) either of function (physical or mental) or of role (within the family, social network or workforce.)" This focus on function provides the context for setting meaningful rehabilitation goals, which may otherwise be difficult to define for such a diffuse set of impairments stemming from brain injuries (Sohlberg and Mateer, 2001).

Total restoration of functions may not be possible for some people, as the physical and cognitive conditions that we have looked at may be such that the can never be fully repaired (Plant, 2002). For example, strokes can irreparably damage the brain through cell damage. Whilst restoration remains the ideal outcome for rehabilitation, realistic goals should be to maximise functional activities and minimise the effects of remaining impairments (Plant, 2002). Rehabilitation activities should therefore involve ecologically valid goals that have meaningful value to a client or those close to them, that build upon an individual's strengths, and equip them with strategies to manage their skills and emotions (Sohlberg and Mateer, 2001).

3.3 Integrative Rehabilitation

There are many different types of therapeutic models, cognitive and behavioural theories, and rehabilitation strategies. Psychologists, speech and language therapists, occupational therapists and other types of clinical professionals bring their own training, preconceptions and experiences to a rehabilitation setting.

Integrative therapy is concerned with using these different approaches as needed to suit the particular characteristics of a client using theory, evidence and technique. It looks to support dialogue between clinical professionals working with different approaches, rather than to combine and apply them indiscriminately (Zarbo et al., 2016). A key descriptor of integrative therapy is that it consists of a multidisciplinary team, where clinical professionals work together towards a rehabilitative goal.

The client is an active participant in the integrative therapeutic approach, where their preferences and characteristics are considered in the rehabilitation process. For example, basing rehabilitation activities around their hobbies or passions (Zarbo et al., 2016).

An integrative approach also emphasises the therapeutic relationship between a client and clinical professionals, where therapists can inspire hope and trust, and work together to facilitate change. This therapeutic alliance has been shown to be a key predictor of change in rehabilitation (Feixas and Botella, 2004; Zarbo et al., 2016).

3.4 Neurobehavioural Rehabilitation Model

Impairments in self-regulation arising from frontal brain injury, defined as deficits to the executive functions, can severely impact upon behaviour. This neurobehavioural disability is characterised by

> *"Patterns of maladaptive behaviour characterised by impulsivity; inappropriate social or sexual behaviour; lack of tact and discretion during interpersonal activities; diminished self or social awareness; an egocentric attitude lacking in warmth and empathy towards others; labile mood with shallow irritability that can escalate into impulsive aggression; poor attention control resulting in an inability to maintain goal directed behaviour; a lack of ability to spontaneously initiate purposeful behaviour; and fatigue, often associated with a lack of drive and motivation." (Worthington et al., 2017, p.4).*

The socio-cognitive and functional behaviours that may be impaired are critical to the ability to live independently and reintegrate as a member of the community.

An integrative neurobehavioural rehabilitation model has been developed that recognises this behaviour-centric disability and incorporates ecologically valid and generalisable behaviour management strategies (Wood, 1987, McMillan and Wood 2017). The model forms the foundations of many rehabilitation practices, including services run by the Brain Injury Rehabilitation Trust, making it of importance in our research with this organisation.

The neurobehavioural rehabilitation model (NRM) has evolved with direct input and feedback from clinical practice (McMillan and Wood, 2017). The focus of the neurobehavioural rehabilitation model (NRM) is on supporting service users to acquire "functional skills, abilities and social behaviours" which are adaptive and support social integration by maximising "personal autonomy" (Worthington and Alderman, 2017, p.16). The model recognises that social cognition and everyday life skills are not mutually exclusive goals; social behaviours contribute to many everyday activities (e.g. talking to a cashier in a supermarket), and everyday life skills afford greater social independence (e.g. less reliance upon caregivers). (Worthington et al., 2017, p.7) reflect this when they describe NRM approach as promoting the "acquisition of functional abilities likely to lead to greater social independence".

A defining component of the NRM is that rehabilitation is not session-bound, but continuously and consistently provides opportunities to develop socio-cognitive and functional behaviours. The organisation of a neurobehavioural rehabilitation service is therefore critical to facilitating successful outcomes. (Worthington and Alderman, 2017, p.19) describe the structure of a rehabilitation service as consisting of four components:

- Physical environment
- Multidisciplinary team
- Daily routine
- Behavioural management and learning theory

3.4.1 Physical environment

Neurobehavioural rehabilitation programmes, with the goal of functional and social independence, gradually expose service users to such independent settings. They are typically not hospital-based, and instead exist as residential centres located in or near the community. Eames and Wood (1989) even suggests that post-acute rehabilitation for people with brain injuries should be “as far as possible away from hospitals” (p.51). They adopt a structured environment that removes service users from the medicinal feel of a traditional hospital – associated with illness – and instead placed them in a social and domestic setting (Chestnut et al., 1999; Goll and Hawley, 1989).

The NRM places an emphasis on ecological validity and generalisability of behaviour to everyday settings. Situating services in community settings is conducive to this goal, as it opens up a range of community-based social opportunities that would otherwise not be available (Worthington et al., 2017). McMillan and Greenwood highlight the benefits of this approach:

> *“The learning difficulties and other neuropsychological deficits that these patients have means that many elements [of rehabilitation] should not be sited at institutions, but in a natural community setting, to emphasise a move towards independence, minimise problems with generalisation to everyday routine and emphasise the educational and training nature of the service.” (McMillan and Greenwood, 1993, p.253).*

The potential for social and functional activities to take place in realistic community settings therefore helps people to learn and apply skills towards independent everyday activities. The NRM can be described as *community-based social rehabilitation.*

3.4.2 Multidisciplinary team

As an integrative therapeutic approach, the NRM incorporates various neuropsychological, cognitive and behavioural theories. It brings together clinical professionals from different disciplines, such as speech and language therapists, neuropsychologists, and occupational therapists, and promotes the sharing of knowledge free from traditional boundaries.

Communication is crucial amongst members of a multidisciplinary team seeking to deliver consistent opportunities and strategies for behavioural change. Members of a multidisciplinary team in any domain must have a "shared meaning" (Davies, 2007). This means that they must be aware of the goals of an individual, their unique circumstances, preferences and characteristics (Worthington and Alderman, 2017).

To accomplish this shared meaning, the frequent exchange of information is essential to an integrative multidisciplinary team. Problem behaviours, strategies, or key events must be frequently communicated as part of an ongoing dialogue between team members. For example, if a rehabilitation strategy is to focus on rude behaviour, all members of the team should be aware so that this behaviour can be watched for in a variety of situations. Similarly, if a service user is seen by a team member to be physically aggressive, other members of the team must be made aware to discuss how this might be observed and addressed.

This collaboration presents challenges, as team members must understand the types of behaviour that are of interest to the group. For example, a service user running a pencil along their arm in a drawing activity is harmless, but a therapist may see this as cause to withhold access to sharp items in a kitchen activity. The specifics of behaviours (such as the exact behaviour or its preceding events) are also important but may be difficult to recall in detail. It is also time-intensive to coordinate and communicate shared knowledge between team members (Worthington and Alderman, 2017).

3.4.3 Daily Routine

A distinction between neurobehavioural rehabilitation and many other forms of therapy is that it is structured through its daily routine (Worthington and Alderman, 2017). Rather than simply attending short therapeutic sessions, service users attend a residential programme where they are supported over a period of time. This means that clinical professionals can witness and support people in a wide variety of living situations, such as when waking up or preparing lunch, rather than just in a tightly defined therapy slot.

This structured and integrative approach is tailored to an individual's needs to cover cognitive, behavioural and physical therapies to treat the deficits introduced by brain injury. Although this may include traditional therapy sessions, such as psychotherapy, socio-cognitive exercises or physiotherapy, it supports skill acquisition for activities that someone would be expected to partake when living independently. In our visits to observe NRM in practice (see Section 3.5), we encountered cooking or laundry activities or group socialising. As a community-based social rehabilitation approach, the NRM also facilitates activities in the community such as crossing the road or going to the supermarket.

3.4.4 Behavioural management and learning theory

A past criticism of behavioural rehabilitation is that it seeks the extinction of problem behaviours through techniques such as punishment, rather than seeking to understand the cause and encouraging adaptive behaviour (McClean and Grey, 2007).

A key characteristic of the NRM is to emphasise effective learning strategies over direct behavioural interventions. This means understanding a service user's mental representation of the world, or their cognitive schema: the mental model developed to describe how the world works. This approach acknowledges the properties of a situation and an individual to properly understand why the behaviour is manifesting (Goldfried, 1983; Barlow and Durand, 2002; Worthington and Alderman, 2017). NRM sees behaviour as a result of cognitive schemata: "it combines elements of both [behavioural and cognitive theories], emphasising the objective characteristics of cognitive processes which are reflected in the behaviour of an individual" (Wood, 1987, p.7).

The ABC model is frequently used to expose elements of a person's cognitive schemata and the meaning behind behaviour (Barlow and Durand, 2002; Sohlberg and Mateer, 2001). It records the:

- Antecedents – the events leading up to a behaviour; the characteristics and experiences of the individual.
- Behaviour – the problem behaviour, which may be challenging (i.e. aggressive or inappropriate) or otherwise.
- Consequences – what happened afterwards; verbal, physical or social responses to the behaviour.

These ABC reports give clinicians insight into the events around behaviours of interest.

McClean and Grey (2007) demonstrate the clinical importance of understanding the meaning behind behaviour. They report a case study of Sarah, a 22 year old woman with challenging behaviour that had included inflicting injuries on support staff. Sarah's behaviour was assessed, including recording the antecedents and consequences of behaviour. These analyses found that Sarah was frequently demonstrating challenging behaviour in groups, or when faced with irregular and non-routine events. Sarah's cognitive model of the world was that she could leave group situations or express discomfort in unplanned situations by exhibiting this behaviour. Interventions were set up to provide her with alone time and better escape strategies. Roleplay exercises using visual storyboards were used to help her plan for non-routine events.

Behavioural management also extends to understanding and supporting executive impairments to socio-cognitive and functional skills. The structured daily routine of the NRM allows clinical professionals to observe and intervene with behaviours on a range of independent living activities, such as getting ready in the morning or preparing lunch. In Section 2.4.2 we looked at three everyday life skills (brushing teeth, making a sandwich and supermarket shopping) broken down into their component tasks, and examined how an executive impairment to any task could hinder attempts to complete the activity. For example, deficits to initiation might leave a person unwilling to start brushing their teeth, or disinhibition could cause the disclosure of too much personal information when talking to a supermarket cashier.

NRM enables clinicians to see how a person's impairments affect their socio-cognitive and functional abilities across such everyday life activities, and work within a multidisciplinary team to devise effective learning strategies to compensate for them. Cueing (or prompting) is one such strategy that can be used with tasks to help complete and learn behaviours over time (Worthington and Alderman, 2017; Sohlberg and Mateer, 2001). For example, if stuck after wetting the toothbrush, a person would be prompted to think about the next step. This might start with direct prompts: "pick up the toothpaste, open it and apply to the toothbrush". NRM seeks the withdrawal of prompts to facilitate independent living skills, so such a prompt could be gradually withdrawn and generalised: "what should you do after you've wet the toothbrush?". The success of such prompting would then be fed back to the multidisciplinary team, such that a consistent level of prompting can be applied across all activities.

3.4.5 Case study

The assessment and treatment of neurobehavioural symptoms requires evidence-based decision making by a multidisciplinary team. The behavioural management and learning theory in a structured community-based environment supports and informs this process. Monitoring a person in ecologically valid situations allows clinicians to determine how someone performs in independent living settings, to intervene and withdraw learning strategies such as prompting, and determine how successful different strategies are.

Goll and Hawley (1989, pp.147-149) present a case study of a 20-year old man, "Mike", whose traumatic brain injury had resulted in attention deficits. Behavioural recordings found that Mike took two hours to complete morning hygiene tasks. He also exhibited inappropriate social behaviour characterised as overly-familiar and physical interaction with others, such as touching and hugging. Once admitted to a community-based social rehabilitation programme, Mike's team adapted their techniques around his individual deficits and personal preferences. Mike was then prescribed an intensive programme aimed at restoring his lost functional and socio-cognitive skills.

Functional behaviour

From 7-8am, Mike was given one-to-one supervision from a therapist who gave him prompts to perform morning hygiene tasks. When the tasks were carried out following the prompts Mike received praise, and when they were not the prompt was repeated. The number of prompts required was recorded on a wall chat for Mike to visualise his progress, as well as to receive direct feedback on his performance. This technique took his impairments with initiating and continuing tasks and sought to address them through the context of a functional skill that is an essential part to independent living.

Socio-cognitive behaviour

Another example from Mike's programme was when he was given the option of how to spend a morning activity. He chose to focus on his social skills, specifically his approach to interacting with people, in the context of buying a magazine from a local shop. Mike and a clinician roleplayed out the scenario of buying a magazine and rehearsed the appropriate ways to behave. One taught strategy was for Mike to put his hands in his pockets as a self-prompt of inhibition, in order to remind him not to touch the shop assistant. Following this Mike went to the local shop to buy the magazine, accompanied by a therapist who could observe and prompt him. This illustrates the integrative therapeutic approach of incorporating the client's preferences in rehabilitation; Mike wanted a magazine and had motivation for performing the rehabilitative activity.

3.4.6 Summary

Activities such as these can be practiced repeatedly over the course of rehabilitation, but importantly they are common situations in which someone will find themselves in once living independently. Performing morning hygiene tasks are an essential factor in looking after oneself. Buying an item in a shop is an important activity, whether it is buying food to survive or luxuries (e.g. magazines) as part of a rich and fulfilling lifestyle in the community.

The two activities presented here were facilitated by the community-based approach of the neurobehavioural rehabilitation model. Observations and interventions of behaviour in morning hygiene tasks were afforded by the structured all-day routine. Role-play of social situations could be performed in the service, but being able to go out into the community gives opportunities to practice social skills in real and generalisable situations. The range of functional and social opportunities available from this approach helps to "consolidate learning and overcome the difficulties of generalising gains" (Worthington et al., 2017, p.9).

These realistic and community settings are used to draw out behaviours that are observable and have clinical meaning in rehabilitation.

3.5 Neurobehavioural Rehabilitation Practice in Brain Injury Rehabilitation Services

The Brain Injury Rehabilitation Trust (BIRT) operates multiple services around the United Kingdom. These services are specialist units which combine assisted- and independent-living facilities with multidisciplinary therapeutic teams. This combination allows BIRT services to deliver intensive and targeted rehabilitation for people who have survived an acquired brain injury, but who require prolonged care to prevent injury to themselves or others. The desired outcome of rehabilitation in BIRT services is for the reintegration of the service user into the community.

In this section we report on site visits to two BIRT services to explore the settings that neurobehavioural rehabilitation takes place in, as well as some of the activities used in clinical practice. We begin by describing the generic properties of the BIRT services visited, then describe some of the challenges that are faced by clinicians in their work towards their goal of restoring independence in the community. All service users, clinical professionals, and services have been either anonymised or pseudonymised.

The perspectives reported in this section were gathered through six visits to the services between 2014 and 2017. These visits took place on weekdays and included initial tours of the facilities. The visits began short – 2-3 hours – and built up, with the last visit lasting several days. The visiting researcher was supervised for the first five visits and was given free access to communal areas by the consultant neuropsychologist on the final visit. We also draw upon published BIRT literature and the BBC documentary "Louis Theroux - A Different Brain", in which service users and families talk about their experiences and challenges whilst working with BIRT after brain injury (BBC, 2016).

Users of the visited services were profiled as those who exhibited challenging behaviour or who had been detained under the Mental Health Act, impacting upon their ability to live independently. These were people whose behaviour might present a risk to themselves or to people around them. The average duration of a person's stay at the services was 7 months, but we met service users who had resided in a BIRT service for over a year. Other service users were described to us, who had stayed for several weeks before discharge. BIRT's Outcome Report 2016 (Disabilities Trust, 2016) presents the case of Duncan, a traumatic brain injury survivor who was admitted 17 years after his injury, and who had spent over 3 years residing at a BIRT service. BBC's (2016) documentary introduces Natalie, who had been in rehabilitation for 15 years for support with memory loss, socio-cognitive interactions, and aggression.

It is important to note that a given service user's rehabilitation did not begin with admission to a BIRT service, not did it typically end with discharge. Service users could be several months or years post-injury by the time they were admitted, and they could be discharged to continue their rehabilitation in the community. Their stay in a BIRT hospital was aimed at achieving a set of goals that would represent meaningful progress towards their overall rehabilitation. BIRT's Outcome Report 2019-20 (Disabilities Trust, 2020) identifies four measures of outcome used to quantify these goals:

- Reduced levels of supervision
- More independent accommodation settings
- Return to occupational or recreational activities
- Improvement in social participation

The fundamental purpose of the services and these outcomes reflect the neurobehavioural rehabilitation model: to re-equip service users with the functional and socio-cognitive behaviours to support social integration by facilitating independence (Worthington et al., 2017). BIRT supports the acquisition of these independent living skills whilst retaining levels of safety and supervision appropriate to the severity of the challenging behaviour.

The Outcome Report also quantifies success using outcomes related to these measures, listing the percentage of service users who:

- Required reduce levels of supervision on discharge.
- Were discharged to a more independent living setting.
- Showed a clinically significant improvement in social participation (Disabilities Trust, 2020).

This reflects the behavioural management and integrative components of the NRM. Service users are treated as individuals and their progress is tracked over time, in order to quantify rehabilitation goals.

3.5.1 Service Description

The visited services were capable of supporting approximately twenty to thirty service users at various stages in their rehabilitation. The services were comprised of en-suite bedrooms, and service users would typically be full time residents whilst receiving round-the-clock care from a team of support workers. Some service users visited their families on the weekends. In addition to these bedrooms, the services featured self-contained flats to help people transition towards independent living whilst retaining the safety and support of on-site care.

During their stay at the services, service users would partake in a range of activities designed to raise their levels of independence. To facilitate a daily routine, each hour of the day was planned out on a whiteboard, including allotted times for sleeping, smoking and rest. This regimented timetable was tailored towards the needs of individuals based upon neuropsychological consultations and progress reviews. In some cases, slots were given over to the service user, allowing them to choose an activity. This highlights the integrative nature of therapy to use service user preferences and motivation in activities, and also provides opportunities for service users to exercise independent decision making.

Some of the activities would make use of on-site facilities such as a kitchen, launderette and IT suite. These rooms enabled the retraining of practical skills that would be required by someone living independently or returning to work. Support workers and therapists would continue to play a role when these facilities were in use; for instance, use of the IT suite would be supervised to ensure that illegal material would not be accessed online, or that inappropriate behaviour did not take place. Assistive technology was integrated throughout the hospitals, such as to prompt tasks in the kitchens, to aid in the transition to independent living.

In addition to the IT suite, gaming consoles were located in communal areas. Some service users were also seen or described as having mobile phones, which they would use for communicating with friends or family, or for playing mobile games.

Community reintegration was described as a vital part of rehabilitation activities at the services. Services included dedicated rooms, each containing sofas, televisions and board games, for families and friends to visit residents. These rooms offered a relaxed environment for service users to spend time with people they might not get to see often and provided a clear separation from the rest of the hospital. These also served as analogues for real world social settings.

Some activities were designed around community-based activities, such as going to the shops for weekly groceries, buying cigarettes, or engaging in hobbies or sports. In such instances, a service user would be accompanied by one or more support workers, or by another member of the clinical team. These extra-hospital activities could have certain preconditions; for example, challenging behaviour could lead to activities being cancelled.

The challenging behaviour of service users, and the inherent risk to others that this entails, was apparent in the services' security measures. Entrances consisted of pairs of locked doors which were unable to open simultaneously, preventing anyone from entering or leaving the building without authorisation. One visited service featured a fence around its garden to prevent people from entering or leaving by other means. The services were also divided up into sections separated by coded doors, and access to rooms such as the kitchen or IT suite was controlled.

Service users' challenging behaviour, progress through rehabilitation, and daily needs were reported and monitored through team meetings. This reflects the integrative and multidisciplinary approach used in a neurobehavioural rehabilitation model, where teams strive for a shared meaning and understanding of goals. The teams drew upon the expertise of a variety of clinical professionals, including but not limited to: speech and language therapists, occupational therapists, neuropsychologists, nurses and support workers. The visiting researcher attended two types of team meetings during his visits:

handovers and clinical team meetings.

Handovers

Observed days in BIRT services began with a morning handover, which was attended by the nurses and support workers who had been on duty overnight, as well as by nurses, support workers, neuropsychologists and other clinical professionals who would be running the service during the day.

Handovers began by reporting upon any important events from the previous day or that morning. The time that service users had gone to bed and woken up was noted, including whether they had been prompted to do so or done this independently.

Information on behaviours and prompting were used to make short-term decisions on clinical practice. For instance, a service user was noted as having poor oral hygiene, so the response was for a support worker to be present when he woke up the following morning to prompt him to brush his teeth. Although the researcher was not present at the following day's handover, it was explained that reporting would be used to assess the strategy's success and look at options such as alternating prompting between days. Ideas on how to broadly support service users' behaviour were also floated during handovers. In one case, it was suggested that magazine subscriptions could be used as a reward token; rather than giving the magazine to someone when it arrived, it could be saved and used to reward good behaviour.

Teams were also briefed on activities for the day, such as advice for support workers to accompany service users out of the hospital (e.g. "bring a picture of her partner in case she needs reassurance"), or specific arrangements for family visits (e.g. "don't leave him alone with his brother"). Any questions over the fitness for service users to engage in the day's activities were also raised.

Handovers fit with the neurobehavioural rehabilitation model, which looks to ensure that every member of the rehabilitation team is aware and involved of progress, strategies and goals (Worthington et al., 2017). As demonstrated by the examples of morning hygiene and magazine subscriptions, it supports the concept that rehabilitation should not be session bound, and should create multiple opportunities to encourage and reinforce functional and socio-cognitive skills Worthington and Alderman (2017).

Clinical Team Meetings (CTMs)

Morning handovers were concerned with the day-to-day operations of the service, and the immediate concerns of caring for and supporting a service user. Clinical team meetings CTMs) took place weekly and involved the long-term monitoring and discussion of clinical needs and plans for service users. They were attended by the consultant neuropsychologist and members of the clinical team. Observed CTMs were attended by three to six members, typically including a neuropsychologist, occupational therapist and a speech and language therapist. Some observed CTMs included more neuropsychologists, a physiotherapist and the senior nurse.

Clinical team meetings demonstrate how evidence-based decision making, behavioural management and evaluation, and learning theory come together in a neurobehavioural rehabilitation approach. The team would discuss each service user at length, firstly taking time to detail their background (e.g. age, cause of injury, time since injury/admission), the challenges they had presented with on admission, and any long-term rehabilitation goals. Each member of the team would then talk about their experiences with the service user over the previous weeks. This was an informal discussion where team members contributed to the overall picture of a service user's rehabilitation, embracing the cooperation and shared vision essential to an integrative approach (Worthington and Alderman, 2017). Strategies were then developed using learning theory and behavioural management, with consideration to the deficits being targeted.

For instance, a service user "Terry" was introduced in a CTM as several years post-injury but new to the BIRT service. He had exhibited some aggressive behaviour in the past that had included time spent in prison. A socio-cognitive deficit that was highlighted was Terry's tendency to disclose very personal details, and one of his rehabilitation goals was to help him stop this disclosure. Clinical professionals in the team highlighted instances of such disclosure on the unit, as well as talk of self-harm. However, a neuropsychologist had discovered through sessions that Terry acted tough but was terrified. Behavioural recordings, similar in nature to the ABC (antecedents, behaviour, consequences) model, were analysed, and the team hypothesised that disclosure and self-harming talk was a coping mechanism for anxiety. The team devised a behavioural management strategy to help Terry cope with his anxiety.

CTMs generally discussed service users' behaviour in two environmental contexts: on the unit and in local community settings. Both socio-cognitive and functional behaviours were reported and discussed in these contexts, and the contexts informed each other. For example, if a service user was described as being rude on the unit, clinical professionals would discuss whether they might be rude when taken off-site into the community. Alternatively, if someone was described as good at timekeeping in the unit, an off-site exercise involving timekeeping would be prescribed to see how they performed in the community. This also reflects one of the goals of neurobehavioural rehabilitation: to support the generalisation of behaviours from specific instances on the unit to habitual behaviours in everyday scenarios Worthington et al. (2017).

Activities taking place off-site and in local community settings were highlighted to us, with clinical professionals describing the benefits, drawbacks and potential as an area of potential innovation. In the next subsection we look at the community activities described to us in handovers, CTMs, and in our general interactions with clinical professionals.

3.5.2 Community Settings

Neurobehavioural rehabilitation for executive dysfunction seeks to restore levels of independent living to support re-integration into the community. Activities that take place in the community, such as going to the supermarket, are essential everyday life skills for someone living independently. In Chapter 2 we described how socio-cognitive and functional deficits can impact a wide range of everyday life skills, including those taking place in the community. Rehabilitation seeks to teach strategies to handle such situations, and community access offers benefits to this. In our NRM case study (see Section 3.4.5) we looked at Mike, a TBI survivor who practiced roleplaying exercises with a therapist before going out to a real shop to try his behavioural strategies.

A key concept in NRM is that behavioural strategies must also be generalisable to a broad range of situations, not just applicable to specific situations in the clinic. In BIRT clinical team meetings, clinical professionals discussed how behaviours on a unit would generalise to community settings. For example, whether poor behaviour on the unit could predict poor behaviour in the community, or whether successful skills (e.g. timekeeping, money management) would continue in community settings such as shops or transport.

Community activities were described by BIRT clinical professionals as a gold standard of rehabilitation practice, that is also fraught with challenges and risks. It offers great opportunities to consolidate learning and generalise behavioural strategies to real and relevant situations that may be frequently encountered in independent living settings. However, the challenging nature of many BIRT service users means that it is not always safe to do so. Service users can be known to be physically or verbally aggressive, which can be managed safely in a BIRT service unit but may be difficult to manage when out in the community. Service users with challenging behaviour can also be unpredictable, so they might exhibit positive behaviour in the clinic but be at risk once leaving it.

Due to this challenging behaviour, many BIRT service users are restricted from accessing the community. They may be allowed to visit local shops but under escort, either by a therapist or a support worker. However, this needs to be scheduled into the daily routine for both the service user and clinical professional, costing time to plan and travel, and money for transport expenses and clinician hours. Service users may decide they want to go out when such time has not been allocated, which might lead to disappointment or frustration. During one visit to a BIRT service, the researcher was approached by a particular service user who wanted to leave the unit:

> *SU: "Can you let me out for fags?"*
> *R: "I don't think I can."*
> *SU: "I don't like you."*
> *R: "Shall we go and ask [consultant's name]?*
> *[SU walks away and comes back a few minutes later}*
> *SU: "Can you do me a favour? Can you go out and get me fags if I give you money?"*

Here the service user wanted to visit the shop and had motivation to do so: to buy cigarettes. This motivation was strong enough to persist and try a different technique by offering money. This might have been a good opportunity for a therapeutic exercise or to practice an independent living skill, but access was restricted and time had not been allotted.

It would be useful to create more opportunities to practice community interactions without these time constraints.

The problem of getting into the community to practice independent living skills was described at various times during our visits to BIRT services. We have broken these down into two discrete challenges:

1. Accessing the community. Being able to use public transport to access amenities located away from the rehabilitation centre.
2. Behaviour in the community. The socio-cognitive and functional behaviours that are exhibited whilst engaging in activities in community settings, such as in a shop or street.

In this section we focus on the challenges of accessing the community. Chapter 5 addresses behaviour in the community.

3.5.3 Community Access

Not all service users have restricted community access. There are some, especially those who are later on in their rehabilitation, who clinicians know are going to be safe and have effective behavioural management techniques. These people might be granted unescorted community access. This is desired for two reasons. Firstly, the clinical goal of rehabilitation is to promote independent living, and having someone able to safely go into the community is a key milestone towards their recovery and eventual discharge. The other is related to the practical considerations of running a rehabilitation service amidst cost concerns and staff resources. It was explained in a CTM that clinicians would like more people travelling independently rather than needing support workers escorting them everywhere, costing time and money to the service. By promoting independent travel, staff could be kept on the unit where they could be more useful. A consultant neuropsychologist pointed out that it was cheaper for BIRT to pay for taxis to take service users everywhere, than to send out support workers. The ideal goal was said to be for service users to be able to catch public transport such as buses.

There are people who clinicians are willing to grant unescorted community access to, but who might have trouble accessing the community. They might be too anxious to get onto public transport. A service user was raised in a CTM who suffered from panic attacks about going into the community alone, and was concerned that she could not remember bus and train times due to memory impairments. Instead she relied on her support workers or husband, but found it difficult when her husband was travelling for work and support worker time could not be scheduled.

As well as being concerned about the effects of their impairments, service users could be concerned about how they will be perceived. Headway's (2013; see Chapter 2) interview with Alex revealed discomfort at presenting his disabled bus pass due to his hidden neurobehavioural disability:

> *"My outward appearance would indicate that there is nothing wrong with me. However, I get a number of suspicious looks from bus drivers: 'How have you wangled [a disabled bus pass]?'" (Headway, 2013).*

The mannerisms of people with neurobehavioural symptoms, where they might be misperceived as someone who is drunk or has taken drugs, can raise suspicions that the person might be sensitive to.

Service users might also just be inexperienced with getting onto public transport. People with acquired brain injuries come from all varieties of backgrounds, so might have been accustomed to driving before their injury. They might have suffered memory impairments that prevent them from recalling the procedure for getting onto a bus. Alternatively, they could have been in rehabilitation for several years without the opportunity to practice getting onto public transport post-injury.

For people with anxiety over their impairments or the perception of others, or who are inexperienced or cannot remember how to use public transport, practice would be useful. BIRT clinicians described how they would use roleplaying exercises similar to those used by Mike to practice buying a magazine (Goll and Hawley, 1989, pp.147-149). Clinicians would set the context for the roleplay, then act as the role of a bus driver or ticket vendor. They would then roleplay out the scenario of buying a ticket, then provide feedback and discuss strategies. The clinician would tailor the “character” they were playing in order to provide different challenges. For example, they might play a vendor as irritable if they thought it would present a challenge to the service user.

However, there are issues with roleplaying exercises. The roleplay is conducted in a familiar setting inside a rehabilitation service, with a therapist who the service user knows and may trust. Being able to practice socio-cognitive activities, such as recognising and responding to emotions, is difficult with a single familiar therapist; a person can become used to reading emotions on a familiar person but struggle to generalise it to strangers in the public. It also remains unpredictable how the person will behave in the real situation, when they are faced with the stimuli of a real environment. Ideally the exercise should be generalised to community settings, as aimed for with the neurobehavioural rehabilitation model. At the least, it should be attempted and practiced in the real world before a person is given unrestricted community access.

Consider the practical problems of practicing getting onto a bus in the real world. There is still a time and cost investment with the need to send a therapist or support worker to supervise the practice. There is little room for error if something goes wrong; in a worst case, there might be a need to deal with confrontation. The service user and clinician might need to wait for another bus to arrive if either purchasing the ticket goes poorly, or if they want to try it again – it is not an easily repeatable activity. The situation is also uncontrollable. For instance, the queue at the bus stop might be long. The clinician may wish to start the service user without a queue so that they do not feel rushed, then gradually introduce a queue with practice. This is exceptionally difficult to do in the real world with real buses and people.

Another consideration raised by clinicians was the facilitation of insight and the role of memory in real world settings. After using public transport, there may not be an appropriate time and place to debrief until back in the rehabilitation centre. For someone with memory impairments, this may be too late to discuss how the practice went and strategies to try for the future. For example, a therapist might want to discuss a service user's interpretation of a person's emotions; this is difficult to do without a picture or recording of the person. Someone with deficits to insight may believe that they have performed well, but the clinician has no recording or evidence to facilitate a discussion.

3.5.4 Summary

Service users exist who may be safe and ready for independent community access, but who need practice to overcome anxiety or inexperience with public transport links to access community areas. Clinicians have described challenges with current strategies employed in clinical practice:

Going out into the community to practice

- Opportunities to do this are infrequent and expensive.
- Someone with challenging behaviour may not be safe to take into the community.
- It is difficult to control the environment, such as start with a simple and quiet environment and gradually increase difficulty.
- Recordings are difficult to take to facilitate discussion and insight.

Roleplaying exercises

- Useful to be able to tailor and vary responses to create challenges.
- However, little opportunity to vary the exercise settings or appearance/voice of the conversational partner.
- Lacking the stimuli of a real environment.

These practical limitations to community access, an important part of rehabilitation, may be facilitated by technology.

3.6 Conclusion

This chapter has sought to explore the theory and practice behind the rehabilitation environment within which we are working, to identify one or more aspects of rehabilitation that might be facilitated by innovative and interactive technology. We have established that the rehabilitation in this domain relies upon an appropriate community-based setting, a multidisciplinary team, a structured daily routine, and behavioural management learning theory. The Brain Injury Rehabilitation Trust implements this neurobehavioural rehabilitation approach, but its work is made difficult by the challenging nature of its service users. Exercises taking place in real world settings are the ideal for behavioural learning to be generalised to everyday life skills but challenging behaviour may preclude real world settings outside of a rehabilitation centre.

Clinicians have described public transport access as a barrier to their work. They would like to introduce service users to public transport over the course of their rehabilitation, either to get them accustomed to its use, to see how they behave in such settings, or to facilitate unescorted community access ahead of discharge. They have outlined the problems with practicing this in the real world, and the drawbacks of roleplay exercises as an analogue.

In Chapter 4 we examine how virtual reality technologies could be used to address these challenges, and to further our collaborative effort with clinical professionals.

Chapter 4

Virtual Reality Prototype for Community Access

4.1 Introduction

Clinical professionals have described the use of public transport as a barrier to community access, restricting some people who have the skillset to go into the community independently, and using up valuable resources to support those people when they leave the rehabilitation centre. Clinicians would like to introduce service users to public transport over the course of their rehabilitation, either to ease anxiety over its use, to get them accustomed to using it after an extended period within a rehabilitation centre, or to assess their safety in those circumstances. The goal is to facilitate unescorted community access ahead of discharge.

They have outlined how this currently takes place in clinical practice. Roleplaying exercises are used to practice socio-cognitive and functional skills such as waiting and getting onto a bus. These offer a high level of tailoring towards a person's abilities, but lack ecological validity; the settings of a rehabilitation centre are more familiar and controlled than a real world setting. However, the act of going into the real world is costly in both time and money, and may not be safe to do.

Virtual reality is suited to situations that require realistic and immersive settings, but that are difficult to re-create in the physical world, are financially expensive, are dangerous to life and limb, or are too time consuming. We therefore propose that it is suited to the socio-cognitive exercises required here.

In the context of our research, we define "realistic" as having some properties analogous to those of the real world, to the extent that it allows transfer of relevant knowledge. Our interest in the social skills training that takes place in rehabilitation programmes sets the rough boundaries for relevance, such that we can more specifically define a "realistic" simulation as one in which communication matches the real world. This extends from speech to visual cues and gestures.

We likewise apply the term "immersive" to an environment in which a user is able to at least partially block out the surrounding world, and that is subsequently treated as a substitute for the obscured stimulus. This immersion should capture a user's attention and motivate them to behave and react as they would in reality.

The controllable and repeatable nature of interactive systems provides a safe, flexible and reusable training environment for these tasks. When looking to create as realistic and immersive a simulation as possible, developments in virtual reality offer an attractive medium for users to interact through (Rizzo and Koenig, 2017).

This chapter presents an overview of virtual reality's benefits and drawbacks within the field of rehabilitation and therapy. It then describes a VR prototype to support rehabilitation activities concerning community access, and some informal feedback from clinical professionals.

4.2 Virtual Reality

Virtual reality (VR), whilst not a new concept, is a field that is receiving increasing attention and growth. VR takes several forms: fish tank VR is typically a stereoscopic image viewed on a monitor and made 3D through specialised glasses. CAVE systems generally surround the user with one or more large screens. The launch of commercially available and affordable VR has seen the proliferation of head-mounted displays (HMDs), worn devices that use slightly offset images projected directly in front of the user's eyes to create the illusion of 3D. Both CAVE and HMDs attempt to fill vision and preserve a realistic scale of virtual objects.

4.2.1 Strengths

The controllable nature of a VR environment is widely seen as one of its major benefits within the context of therapy (Rizzo et al., 2004; Gorini and Riva, 2008; Bohil et al., 2011; Adamovich et al., 2009). The content – events, items, characters – of the environment can be selected with a particular scenario in mind, unlike the unpredictable nature of the real world. Controlling stimuli also allows the targeting of particular behaviours and limitations, which is difficult to achieve in complex multisensory real world scenarios. Control has further implications on factors such as cost, repeatability, and exposure, so is an underlying theme in this discussion.

The interest of the gaming industry in VR has driven technical advances which could benefit other application domains. Graphics cards and controllers developed for gamers have been integrated into VR applications, furthering the capability and quality of virtual world simulations that may transfer to rehabilitation technology. The decreasing cost of hardware and quality of applications being developed for gaming are therefore ideal for the continued growth of VR in fields such as rehabilitation (Rizzo and Kim, 2005). Tools for independent developers also facilitate the creation of good-quality games without the involvement of established gaming companies, which in turn allows more accessible creation of VR scenarios.

Ecological validity is the match between performance in a controlled environment and the settings it models. Therapists require that performance in a controlled environment maps to complex challenges in the real world. The capacity for VR to deliver complex multisensory stimuli in realistic, functionally relevant settings therefore greatly enhances its ecological validity. Despite the high quality of graphics that can be achieved with today's technology, the graphical realism of virtual environments is second to the activities users can carry out there. Provided that a resemblance to the real world is there, user interaction is responsive and the appropriate challenges exist, users are willing to suspend disbelief and react as if the scenario is real (Rizzo et al., 2004).

On top of being able to provide ecologically valid scenarios, VR is able to deliver and control stimuli within environments that would be otherwise difficult to reproduce (Rizzo et al., 2004; Adamovich et al., 2009; Rizzo and Koenig, 2017). Simulation of an aircraft landing is a solid example of the benefits of VR in addressing these difficulties, and is often mentioned in literature (Gorini and Riva, 2008; Bush, 2008). In order for a user to experience an aircraft landing, they must go through all activities leading up to this: arriving at the airport, going through security checks, boarding the aircraft, taking off, sitting through the journey. The landing is a small component of the flight that cannot be repeated easily, and incurs significant costs each time as a result. A private aircraft could be used to repeatedly take off and land, but the costs of doing so make this unviable in many situations. A VR simulation of a landing can be repeated as many times as required, without the overhead activities involved. The costs incurred here are for the equipment and software needed for the simulation, a one-off cost rather than those incurred every time a flight is booked.

In addition to cost, and the availability and repeatability of specific components of flight, control is again a benefit. Factors such as crews, aircraft model and weather can be adapted easily in a VR simulation, but would require time and effort in the natural world (Powers and Emmelkamp, 2008). Weather in particular is impossible to control; simulating a night-time blizzard in the UK on a summer's day in June is easily doable in VR. These are examples of how simulations can put people through events, and alter many different variables, with a high degree of safety (Rizzo et al., 2004).

4.2.2 Limitations

Flight simulation is a convenient example of how much more cost-effective VR simulations can be than real world activities. Rizzo and Kim (2005) pointed out that there was a lack of cost/benefit proofs for other applications in the early 2000s. Even then, the proofs in areas such as flight or military applications made the investments worthwhile. When considering therapy and rehabilitation, we are dealing with less quantifiable measures, but the enormous reduction in cost for high quality VR systems mean that cost is no longer a significant limitation. Nevertheless, research time remains a significant cost in clinical contexts such as those covered by this thesis. There is a risk that a lack of definitive cost/benefit proofs could deter investment into research; such research is however vital in determining what those proofs might be. Hypothesising some of the qualitative measures of benefit VR systems could bring, in lieu of cost/benefit proofs, is a goal of this review.

Another perceived threat to the development of VR system for rehabilitation and therapy is the immaturity of engineering processes (Rizzo and Kim, 2005). A successful environment will require the combination of many factors such as tracking, graphics, psychology, simulation and more. Advances in technology mean that many technical aspects are now more accessible to developers. The integration of VR with game engines now dictates that knowledge of appropriate development tools is sufficient to build a working VR simulation. What remains important here is a multidisciplinary and user-centred approach to ensure that whatever system is built meets the requirements of its users.

Many users describe experiencing cybersickness, a collective term for the symptoms of malaise brought on by the use of virtual environments. Cybersickness induces a range of physiological symptoms that are typically associated with motion sickess, including nausea, dizziness and vomiting (Yildirim, 2019). It is often termed as a "visually-induced" type of motion sickness – there is no external physical motion contributing to the onset of symptoms, rather these arise from the visual observation of motion (Weech et al., 2019; Rebenitsch and Owen, 2016). Along with the physiological responses to cybersickness, Weech et al. (2019) describe behavioural responses such as ending a virtual reality session early. In a meta-analysis of virtual reality experiments, Saredakis et al. (2020) found an early termination rate of 15% across studies that reported these dropouts. Cybersickness has also been hypothesised to have negative impacts on cognitive performance (Nalivaiko et al., 2015; Nesbitt et al., 2017) but other studies have found this effect to be minor and suggested that alternative contributors should be explored (Mittelstädt et al., 2019; Szpak et al., 2019). Cybersickness as a general term can be used in the context of screens, not just the HMDs that exemplify current commercial VR kits (Rebenitsch and Owen, 2016). "VR sickness" is a term specific to discomfort experienced from HMD use (Saredakis et al., 2020) and encompasses the same symptoms as cybersickness – HMDs can induce these to a greater extent than desktop displays or larger screens (Yildirim, 2019). These symptoms of VR sickness can be categorised as nausea, oculomotor (visual discomfort or disturbances, difficulties focusing and concentrating), and disorientation (Saredakis et al., 2020). VR sickness is both a limitation and risk in our work: the early termination of a virtual reality session would interfere with the rehabilitative goals of that session, and negative physiological responses would harm trust in the technology from both service users and administering clinicians.

The factors contributing to cybersickness and VR sickness are complex and continue to be investigated. Sensory mismatch is the most common causal theory (Rebenitsch and Owen, 2016), where the visual and auditory cues of a virtual environment differ from the proprioceptive and kinaesthetic sensations experienced by a user. Factors leading to susceptibility have been proposed that can be classified into three categories: *human factors* (demographics, experience, physical attributes); *hardware factors* (screen, tracking); and *software* or *content factors* (movement, visual cues, information grounding users to the real world) (Rebenitsch and Owen, 2021; Chang et al., 2020). Although there are well-supported factors such as habituation, exposure time, and field of view, susceptibility to cybersickness is generally due to a variety of factors that are further open to variations caused by affect and health (Rebenitsch and Owen, 2021). Further research is needed to understand the implications of these factors to work safely with clinical populations who may experience such health variations and individual differences (Saredakis et al., 2020). An integrative approach comes from Rebenitsch and Owen (2021) who propose guidelines such as habituation, session frequency and length as strategies to reduce cybersickness. Such guidelines would have implications for clinical groups and the design of sessions they participate in.

The advancements in visual and auditory cues afforded by immersive head-mounted displays and acoustic sound simulation provide a compelling VR experience, but raise a further limitation. Smell, touch and taste are sensory stimuli lagging behind visual and auditory interaction (Bohil et al., 2011). Although haptic technologies exist (Adamovich et al., 2009; Geijtenbeek et al., 2011), smell is an area that is beginning to see attention. Olfactory stimuli have the potential to alter emotional state, and smell-related memories are long-lived and invoke stronger emotions that those brought on by other senses (Ramic-Brkic and Chalmers, 2010). However, our understanding of how smells match up with experiences is limited (Obrist et al., 2014). People perceive and identify smells in unique ways, and our knowledge of how to model diffusion of smell in virtual environments is flawed (Ramic-Brkic and Chalmers, 2010). If successfully done, though, smell in VR environments can detract from visual discrepancies by making users less aware of graphical quality (Ramic-Brkic et al., 2007). Taste remains an under-researched sense in VR, but was receiving increased attention at the launch of commercial VR (Chalmers et al., 2009; Ranasinghe et al., 2013). Adamovich et al. (2009) state that the full potential of VR will be known once multisensory interaction in VR is understood, and that research should seek to address this.

4.3 Previous Work

Understanding what has been attempted in the use of virtual reality for rehabilitation and therapy is key to developing an innovative and forward-thinking system. It is not just a question of what does work, but what approaches have failed or could be improved. An analysis of the literature will help to identify areas to explore in the development of a VR system. We begin by examining some specific areas that VR technology has been used to address, and move on to considerations we can take from previous work towards the design and implementation of a system.

4.3.1 VR Exposure Therapy (VRET)

Exposure therapy is an area that is often discussed as suitable for VR, and exhibits its benefits well. Along with other CBT techniques and medication, exposure therapy is one of the most effective treatments of anxiety and is commonly used for phobias. However, there are times when in vivo exposure is not possible. The scenario might be too difficult to reproduce, such as flight, which incurs large costs. Some people may also be too afraid for in vivo exposure (Powers and Emmelkamp, 2008). In this case imaginal exposure is used, where service users are encouraged to picture the situation that they are nervous about. However not all service users are able to imagine the situation to the extent that it brings on their anxiety – a major issue in imaginal therapy. VR can be used to aid the recreation of these experiences (Bohil et al., 2011).

Virtual Reality Exposure Therapy (VRET) can be used as an alternative to in vivo exposure, where service users are placed into the conditions they fear (Bohil et al., 2011; Gorini and Riva, 2008; Bush, 2008; Botella et al., 2017). There is evidence that VRET is as effective as in vivo exposure, which is considered to be the gold standard for this type of rehabilitation (Anderson and Molloy, 2020; Botella et al., 2017). Although the capacity of VRET to deliver ecologically valid and safe exposure to stimuli is acknowledged, there still remains further work to prove efficacy and clinical outcomes for specific disorders (Emmelkamp et al., 2020; Kothgassner et al., 2019).

Being too afraid for in vivo exposure can also be handled through dosage control. In VRET this can be achieved by controlling the intensity, frequency and quality of exposure, instead of needing to find situations with a low degree of exposure to gradually reduce anxiety (Gorini and Riva, 2008; Bohil et al., 2011). VRET therefore enables a hierarchical delivery of exposure, in which service users start at a simplistic level then rise up as they feel more comfortable. This allows the creation of challenges that are most attainable for the service user in their current state of treatment. For example, someone afraid of driving could start off with simple tasks and build up to going on the road (Rizzo et al., 2004). Kaussner et al. (2020) demonstrate this with users with PTSD-related aversion to driving following a critical event in traffic, reducing fear and avoidance to incrementally difficult scenarios. A similar example could be for someone in a shop, where they start off alone with an easily-accessible magazine to buy, before eventually interacting with a complex shop with lots of customers. The virtual nature of VRET also avoids any embarrassing situations for service users throughout this adjustment, until they are ready to go out into the complex environment of the real world (Gorini and Riva, 2008).

VRET enables the use of functionally relevant locales such as city streets, rather than clinics, without any of the control loss that would come from going to these places. Bohil et al. (2011) and Rizzo et al. (2004) also note the consistency that comes from this, and its difficulty to reproduce in the natural world. Although described as a positive thing, it is this lack of reproducibility that should question whether such consistency is good. The ability to train someone through a particular scenario with the exact same events and stimuli certainly has its advantages. However the real world is unpredictable and inconsistent, and it is necessary to prepare service users for this. Consistent scenarios could therefore be preferable for the early stages of VRET when gradual exposure and training is taking place, but later on in therapy the inconsistent nature of life should be sought.

With VRET, service users can repeatedly practice for the situation, and gain positive reinforcement of their compensatory strategies (Rizzo et al., 2004). They can also over-practice by being placed in situations worse than those they are really likely to experience. Gorini and Riva (2008, p. 217) note that this can lead to confidence and a "sense of mastery" at being able to handle the situation. Care should be taken, though, not to reinforce the anxiety by repeatedly putting service users into exaggeratedly difficult and uncomfortable situations.

Exposure therapy conducted through VR also allows therapists to observe service users in ways they would otherwise struggle to. Monitoring equipment can gain insight into the physiological state of the service user, without the need to transport it around. The scenario can also be paused for discussion, where the therapist and service user can stop to evaluate what is going on, talk about the stimuli being presented, and see what might be influencing reactions. Therapists are able to see what the service user sees by watching the virtual environment from their perspective, enabling the identification of the affecting stimuli (Gorini and Riva, 2008). They can also enable service users to view the environment from other perspectives, such as by watching a replay of themselves performing a task from an avatar's view (Lindner et al., 2021). Such playback is useful for a group that may catastrophise situations, have difficulty critically analysing their performance, or lack awareness and insight such as the people with executive impairments this thesis is concerned with.

VRET work has taken place with a range of disorders including PTSD, agoraphobia, phobias and general anxiety (Meyerbröker and Morina, 2021; Anderson and Molloy, 2020). It has also been found to be effective with public speaking (Bohil et al., 2011; Lindner et al., 2019). There are practical benefits to both service users and clinicians when administering exposure therapy in virtual reality, but further controlled trials are required to prove efficacy for specific disorders (Emmelkamp et al., 2020; Kothgassner et al., 2019). In addition, research should consider the therapeutic alliance that exists between service users and clinicians and seek to work with these groups to understand how to foster this relationship (Emmelkamp et al., 2020; Botella et al., 2017).

4.3.2 Practicing everyday activities

Due to the practical advantages of performing activities in virtual reality instead of the natural world, VR is an attractive setting for the practice of everyday tasks. There are several reasons we might wish to do this: firstly, a test of basic living skills enables clinicians to assess a service user's fitness to return home and identify deficits to flag up with a carer. Secondly, the development of compensatory actions allows for the expansion of abilities in spite of impairments.

A further reason for simulating everyday skills is for diagnostic purposes. Mesa-Gresa et al. (2011) demonstrate how a VR system can be used to aid in the identification of ABI service users suffering from unilateral neglect. Diagnosis is usually made through observation or further evaluation techniques. The system used by Mesa-Gresa et al. is intended as a complementary tool for therapists making this assessment. Study participants were required to undergo a street-crossing exercise, in which a two-way-traffic road was displayed on a widescreen PC monitor in front of them. A head tracking system altered the perspective on the screen when the service user looked to the left or right. The goal of the exercise was to cross several streets in order to reach a shop and return with fewer than four road collisions; these collisions were signalled through audiovisual feedback. The study showed this to be a valid tool to aid in assessing unilateral neglect in service users. However, whilst the audio and tracking elements of the system are positive, the delivery of visual data could be improved. Turning to the side is an intuitive way to alter perspective, but to have this perspective displayed at a static location relative to the user is far less natural. It requires the user to maintain eye contact with a monitor at the edge of their field of view, which is inconsistent to how they would naturally perceive a street. This can be compensated for by exaggerating the perspective shift so that slight movements allow for greater fields of view, but this is again not in keeping with natural vision. This is therefore a limitation of using VR displayed on a screen rather than an immersive headset.

When assessing basic living skills, it is important to consider what is being tested. A meal preparation VR system from Zhang et al. (2003) is an example of this, where traumatic brain injury service users' kitchen skills were evaluated. Visual and audio cues were used to prompt users to carry out tasks such as making a sandwich or soup. The system was shown to be a good predictor of real kitchen performance. However the VR system was delivered through a PC screen and input carried out via mouse clicks. Whilst this is therefore a good indicator of whether someone is aware of the order in which to make soup, and the necessity of cues in order for them to do it, more could be done for transferability to the real world. For instance, determining whether someone can safely operate a stove requires more than clicking on it, allowing for better assessment of independence. Haptic technology in an immersive VR system could help here.

Navigation is also an everyday task that can be applied to VR (Bohil et al., 2011). It is made up of two distinct components: *locomotion* and *wayfinding*. Locomotion refers to the technique used to traverse a virtual environment, which may be the physical act of walking in a sufficiently small environment, or an interactive paradigm where this is not feasible. We review locomotion in Section 6.4.2 when describing the development of the Virtuality Street environment. Wayfinding refers to the cognitive processes involved with navigation and spatial learning, where a mental model of the world is built and monitored to select and execute a path (Bowman et al., 2001). Service users who are dysexecutive may have difficulties with the initiation, planning and monitoring of such wayfinding activities – we will look at the clinical interest in paths in Chapter 5 – so this is an important everyday skill in the context of our work. Weniger et al. (2009) report the use of fishtank virtual reality to test how well service users with parietal cortex lesions navigate through a virtual park with static landmarks, and a similarly-sized maze with no identifying features. The virtual environment was found to be suitable for investigating wayfinding and supporting the observation and self-reporting of navigation strategies. In particular, it demonstrated that service users with parietal cortex lesions were able to employ allocentric strategies in navigating with landmarks, but exhibited impaired performance when using egocentric strategies to find their way through the maze. Although our work is with a different clinical population, this demonstrates the capacity of virtual reality environments to expose clinically significant instances of navigation-related behaviour through observations and facilitating self-reporting of wayfinding strategies.

Ewart and Johnson (2021) report a wayfinding task that has direct comparison to a real world environment, consisting of a virtual environment built to mimic a specific university building. The capacity to record and describe wayfinding behaviour is demonstrated by the recording of paths on floorplans, followed by interviews to understand the reasoning behind wayfinding strategies. Such interviews give valuable context to observed behaviours, such as clarifying whether a seen pause was caused by confusion, and should be used when appropriate in our research to better understand user behaviour. Ewart and Johnson's work demonstrates transferability of route finding and pausing, but highlights some discrepancies in perceived speed (with VR seeming slower) and reduced head movement compared to the real world – such transferability (or not) should be considered when interpreting wayfinding behaviours.

4.3.3 Motion-based interaction

How users interact with any system is a vital consideration for designers, and VR systems are no exception. The use of motion-sensitive hardware, where users hold or interact with tangible objects such as the Wii remote, had been explored for virtual rehabilitation pre-commercial VR (Alankuş et al., 2010; Albiol et al., 2012). Modern virtual reality systems typically include controllers (motion tracked and often with buttons) that developers can use to design interactions for games or VR experiences. These buttons generally do not afford complex interactions; for example, users could use "grip" buttons to hold an object but be unable to adjust grip strength without the use of other buttons (Bonfert et al., 2019). Holding objects in this way also gives them a shared and invariable weight (the weight of the controller being held) which is an inaccurate perception of the world that can affect immersion and presence. It is possible to create the illusion of weight by manipulating tracking data so that users need to exaggerate movements to lift "heavier" objects (Rietzler et al., 2018). Virtual objects can also be mapped to real world objects, such as cups, to give them a realistic weight (Simeone et al., 2015). Aside from buttons, controllers afford interaction through tracking of the controller itself, which is primarily driven by wrist and arm movement. These movements, even when coupled with the use of buttons, lack the finesse and precision of the human hand; alternative controllers such as pens may afford more precise interactions (Li et al., 2020).

Considering the types of interactions that controllers may afford with virtual objects may be important in the context of our work, where we expect transferability of skills to be of interest to clinicians. Simplistic interactions with controllers may be sufficient for the types of interactions that we design for clinical rehabilitation, but we should be hesitant when making use of buttons that service users could struggle to generalise to or from real world applications.

Tactile feedback from objects is an advantage of controllers, giving users an additional layer of immersion. However they should also be used with caution with participants in our clinical population who may have comorbidities. A participant in Alankuş et al. (2010) often involuntarily, and painfully, closed her fingers around an object she was holding, so preferred not to have anything in her hand. Hand-held motion-sensitive hardware could therefore be inappropriate for her, or would need to be strapped to her arm instead.

4.3.4 Feedback for insight

Users of virtual reality simulations are not just observers, but actors in the environment. As actors they require feedback about how their actions are affecting the world, and what is happening around them (Klinger et al., 2010; Gorini and Riva, 2008). For instance, crossing the street in a simulation might offer auditory feedback as well as visual feedback, such as in Mesa-Gresa et al. (2011).

Presenting a third-person perspective of moving around can be considered helpful by people trying to improve their gait (Adamovich et al., 2009; Lozano-Quilis et al., 2013). Lozano-Quilis et al. implicitly use this technique when showing users themselves with virtual objects imposed around them. As users move, they can see themselves from different perspectives and gain feedback on their movements that they would not get in the first person.

The importance of giving feedback on movement is demonstrated in Albiol et al. (2012). Users were presented with a virtual rehabilitation environment and asked to use it with and without feedback. Feedback was delivered through the use of footprints representing their feet location within the world. The study reports that this feedback increased both users' presence and immersion within the environment. It is worth noting that only the positioning of participants' feet was used in interacting with game objects. Cameirão et al. (2010) show how feedback of arm positioning and orientation is useful for touching objects in the game world, taking away the need for users to guess where their "hands" are in a virtual environment.

Work by Lindner et al. (2021) (see Section 4.3.1 on VR Exposure Therapy) demonstrates how insight can be facilitated through objective feedback. People experiencing public speaking anxiety gave a speech to a group of virtual characters, rated themselves, and then watched the speech back through the eyes of a character. This type of feedback gives users with diminished insight the opportunity to objectively view their behaviour, and to work with a clinician to reflect upon performance with clear recorded instances of behaviour that both parties can see. This could be invaluable when working with service users who may not trust their own perception of ability, or conversely the perception of a clinician.

The idea of a feedback loop, the two-way flow of feedback between the user's actions and the state of the world, is key to considering users as actors in the system. Geijtenbeek et al. (2011) present this as the "real-time feedback loop" (p.201), which returns feedback to the user based upon the behaviour they exhibit. Their D-Flow virtual reality system makes use of input from treadmills, motion tracking, haptic devices, and other sources capture the user's behaviour, and delivers feedback through surround sound, projections, and motion platforms based upon this behaviour. The real-time delivery of stimuli in response to actions is used to deliver an immersive rehabilitation environment.

4.3.5 Senses

The stimulation of senses in VR is often focused on visual – and to a lesser extent auditory – stimuli. Audio has been used in VR for feedback (Mesa-Gresa et al., 2011; Geijtenbeek et al., 2011) and cues (Alankuş et al., 2010; Adamovich et al., 2009). Tactile feedback has received work in VR, however faces limitations: the human hand contains tactile sensors much more advanced than the gloves used in VR (Chalmers et al., 2009). Smell and taste have notably lagged behind the other senses (Bohil et al., 2011).

Reger et al. (2011) successfully used olfactory stimuli in Virtual Reality Exposure Therapy (VRET) for active duty military personnel with PTSD. Smells associated with a combat arena, such as weapons fire and burning rubber, were delivered to coincide with the audiovisual stimuli being used. Although tactile feedback was not given, users interacted with the world through a joystick built into a fake rifle, giving some sensation of holding a weapon.

Diffusion of smell in a VR environment was modelled by (Ramic-Brkic and Chalmers, 2010). After comparing how smell travelled in a room with participants to a computer model of smell in a virtual room of equal layout, Ramic-Brkic and Chalmers determined that more accurate models of smell are required. This work would be necessary for accurately determining whether a person is able to detect a smell and its intensity; simulations that simply require the presence of smell as determined by a clinician, as in (Reger et al., 2011), would not.

Ranasinghe et al. (2013) present the Digital Taste Synthesizer, designed to invoke the sensation of taste without the use of chemical agents on the tongue. Instead, electrical and thermal stimulation of the tongue are used to simulate sensations such as minty, spicy, sour and more. The hardware used to simulate taste, however, is cumbersome and invasive. For the purpose of the study by Ranasinghe et al., where the objective is to simulate taste, this is not an issue. In conjunction with VR, placing electrodes or other equipment on the tongue could break immersion and present difficulties with movement and speech.

From our review of the brain injury domain, we do not expect olfactory or taste senses to be incorporated into design work within the scope of this thesis, but we acknowledge that they exist on the periphery of VR work. Should they be identified as critical, or even desirable, to rehabilitation efforts then we shall explore non-audiovisual sensory simulation, although cost of equipment remains a significant limitation in clinical contexts. As an alternative to technical solutions, Harley et al. (2018) encourage the use of non-digital stimuli, such as grass or sunscreen, to improve sensory experiences at a low cost.

4.3.6 Customisation

VR carries a stigma of requiring specialist technical knowledge in order to implement. The uptake of VR by the gaming industry can be said to have eased this requirement; game development tools, which is aimed at both amateur and professional game developers, are becoming increasingly compatible with VR technology. Nevertheless it remains true that knowledge of these tools, along with deeper understanding of virtual world development, is essential to building a successful VR simulation.

This is an important consideration when developing VR systems for rehabilitation, where the end-users include service users with very individualised requirements. It is hypothesised in some previous work that tailoring to the strengths and deficits of the individual would improve rehabilitation results (Alankuş et al., 2010; Cox et al., 2010). The clinician is likely to be the best-informed person to customise simulations with a service user's needs in mind, and a range of technical knowledge should be accordingly assumed. If a system is to enable clinicians to customise a simulation the appropriate interface should be given, no matter how well-developed the rest of the system is.

In some cases, customisation might be the high-level selection of pre-programmed alterations to a simulation. One example of this could be difficulty selection, where the parameters of a simulation are tied to the selection of "Easy" or "Difficult" (Albiol et al., 2013). Ease of use here comes at the cost of reduced control, yet this is customisation. An alternative would be selecting from a set of simulations. Lozano-Quilis et al. (2013) enable this customisation by allowing clinicians to select the exercises that a service user will carry out. This is simple to use, leaving all complexity with the programmer, but relies on a designer correctly anticipating what an end-user clinician will want from the system.

In their VRET simulation to treat PTSD, Reger et al. (2011) customised scenarios in real-time to resemble each service user's traumatic event. Two general scenarios were used, simulating a convoy and a patrol, but parameters such as time of day, location, and armaments involved were tailored. Customisation towards this type of personal event is considered to work well with techniques such as imaginal exposure (Reger et al., 2011).

4.3.7 Summary

Virtual reality technology comes with many potential advantages that make it suitable for use in a number of applications related to rehabilitation and therapy. Its controllable and repeatable nature make it particularly suitable for ecologically valid simulations of everyday activities that might not be possible in the natural world. It is important to consider the current limitations and drawbacks of VR as much as its strengths, however, as well as to maintain an eye towards it as a rapidly evolving field.

A review of previous work in specific rehabilitation domains has shown various approaches towards VR in this area, and highlighted some of the strengths and drawbacks associated with them. There are considerations here that should be taken forward in the design and implementation of a VR system.

4.4 Design and Prototyping of the Virtual Bus Stop

Our review of the theory and practice of rehabilitation has identified public transport access as a barrier for clinicians and service users. There also exists a gap between the domains of human computer interaction and clinical psychology. We must bridge this gap such that we as HCI researchers and clinical psychologists can share knowledge with confidence that it is being interpreted correctly. To these ends we have started developing an experimental platform on which to work.

This prototype is the accumulation of knowledge from HCI and clinical neuropsychology, put together as an evolving package that can be used by both domains to verify research direction and further project goals. As our joint understanding of the clinical world develops, we expect our prototypes to evolve to to reflect this knowledge.

4.4.1 Storyboarding

In reviewing literature around the neurobehavioural rehabilitation of acquired brain injuries, we developed a picture of the activities that might take place in post-acute rehabilitative care. In particular we used Goll and Hawley case study of Mike, a twenty year old male suffering from attention deficits after a traumatic brain injury (Goll and Hawley, 1989, pp.147-149). This case study describes Mike's admittance to a transitional living programme within a residential centre.

The goal of this programme was to provide a structured and social domestic environment to build levels of independence and promote reintegration into the community. Cognitive, behavioural and physical therapies were adapted to Mike's individual needs, along with an overarching focus towards resuming activities of daily living. Within a typical day's structure, Goll and Hawley describe various activities such as social skills training, in which Mike role-played out situations with a clinician. One notable example from this training was Mike's tendency to be over-familiar with other people and subsequently attempt to touch them; a technique developed with a clinician was to place his hands in his pockets as a way of making him conscious of their location (Goll and Hawley, 1989, p.149).

This story helped to build our first view of clinical practices for brain injury rehabilitation, particularly in relation to social skills training. In order to challenge and refine this perspective we presented our understanding of a clinical session, framed by the case study of Mike, to our clinical partners in our first visit to a BIRT service. Their feedback enabled us to refine our understanding of how rehabilitation sessions work.

Following this we were able to create a basic storyboard which encompassed our understanding of what a clinical session might look like with a virtual reality component to it. The purpose of this was two-fold. Firstly it would contribute to our design work by allowing us to envision how a virtual therapy session would play out, and highlight any issues that may arise before prototyping began. Secondly it was shown to the clinical team to check that our model of a session's structure remained accurate, and to affirm that their expectations of a virtual therapy environment were in line to our own. The repeated validating of our understanding of a clinical session is deliberate, as we want to make full use of the clinical expertise available and ensure that we do not misinterpret or deviate from existing working practice.

"Aaron" (our hypothetical service user) is a male in his mid-twenties whose executive dysfunction has left him with, amongst other things, awareness deficits. He is attending a social skills training session with Barbara, our clinical psychologist (Figure 4-1).

After a briefing on the activity, Aaron is instructed to put on a virtual reality device. The virtual environment is visible to Barbara, enabling her to keep track of what is taking place during the session.

Aaron is placed at a bus stop, where he might encounter a number of virtual characters who could exhibit certain behaviours or engage him in dialogue.

Challenges that could be initiated include asking someone when the next bus is, or fielding questions from an aggressive drunk. In this case no such encounter occurs, and when the bus arrives he gets on.

Aaron is confronted by a bus driver who appears to have a low mood. Aaron states

Figure 4-1:
Storyboard of a social skills session that might use VR.

verbally that he is going to the train station, which is heard by Barbara.

Barbara selects an appropriate response using a tablet or computer, and this utterance is "spoken" by the bus driver within the virtual environment.

Once the conversation has concluded the bus drives off. Aaron removes the virtual reality device and has an opportunity to reflect on the experience with Barbara. Here he is noting that the driver seemed rude.

Barbara makes suggestions as to how the encounter might have played out differently, and Aaron has the chance to immediately retry the scenario. Barbara may set the parameters to be slightly different - in this example the people waiting at the bus stop might have changed.

This storyboard of social skills training in virtual reality was developed to illustrate our expectations and understanding of how a virtual reality session might take place in practice. A service user would be briefed, attempt a task in virtual reality, reflect upon their experience with a clinician, and then use the virtual environment again to attempt strategies. We presented this storyboard to the clinical team to check that their expectations and ours were aligned, so that any deviation or misunderstanding could be identified and resolved. This is an integral part of the user-centered design approach adopted throughout this thesis, where we demonstrate our understanding of an element of clinical practice, and refine that understanding through discussion with a clinical team, thereby keeping our work grounded in the target domain.

4.4.2 Prototyping

Having established and validated a preliminary design for a virtual therapy environment we began to develop a prototype. The prototype serves three purposes: firstly to provide a test bed for us to try new ideas and techniques, secondly to validate research through studies, and finally to form part of the bridge between HCI and clinical neuropsychology. This last point is a continuing theme from our previous work, where we have strived to involve the clinical team in design to ensure that we are working towards a mutual goal.

The prototype was built using version 4.6 of Unity 3D[1], a game development tool used by professional and independent developers alike. The tool's availability and appropriateness for independent developers also made it appealing for a lone developer to work with. Its support for a wide range of industry formats, and its large online community, meant that the opportunity to obtain resources for development was considerable: a time saver in prototyping. Finally Unity's compatibility with virtual reality headsets bolstered its appeal.

Our interest in virtual reality technology for rehabilitation meant that a medium with which to view an environment needed to be determined. Along with the option of using a monitor or projector, we decided that a head-mounted display (HMD) would help us to assess the state of the art in virtual reality and provide opportunities for assessing its immersive properties. The research team was in possession of an Oculus Rift DK2[2], which at the time of development (early 2015) was one of the few high-end virtual reality headsets available. It was capable of mirroring visual output to a screen, which was crucial when demonstrating prototypes to interested clinicians as it would enable them to visualise a user's experiences. The DK2 was in possession and so

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[1] https://unity.com/ [accessed 19-07-2021]

[2] https://oculus.com/ [accessed 30-07-2021]

Figure 4-2:
Virtual Bus Stop prototype being used.

would not require new purchases from a budget-constrained clinical project, and was capable of prototyping interactions that simulate everyday activities. For these reasons we selected the DK2 for our prototype work.

The virtual therapy prototype is made up of two sub-systems:

- Virtual Environment - the simulated environment containing characters and objects mimicking their real world counterparts.
- Clinician User Interface - a tool which can be used to set up and control the virtual world.

Here we will outline the implemented features of the prototype and summarising their functionality.

4.4.3 Virtual Environment

The virtual environment is a recognisable facsimile of the real world that aims to mimic scenarios through the use of virtual people, objects, physics and other stimuli. The VE is not a complete world; that is to say that it represents a finite space and uses various techniques to give the appearance of a real location. For instance, a five story building might not be fully traversable or contain virtual people performing tasks. Alternatively a building appearing to be in the distance may just be exploiting perspective to create

Figure 4-3:
A view of the bus stop environment. The camera icon shows where the user starts

the illusion of a larger landscape. Techniques such as these are common in virtual worlds to keep the development and computational requirements of environments manageable.

The Virtual Bus Stop Scenario is as validated through storyboarding. It features a generic street with a bus stop and minimal decorations. The user begins at the bus stop as a bus arrives and opens its doors, at which point the user can board and interact with the driver.

The scenario is a low-clutter environment designed to test some of the early design concepts. Pedestrians and ambient noise have been added to attempt to create the daily buzz of a street, however the focus has been on the fundamentals - walking onto a bus and communicating.

4.4.4 Clinician User Interface

The Clinician User Interface is intended to give the clinician intuitive and quick control over the Virtual Environment, without the technical expertise required to use professional development tools. One element to this is the ability to adapt to something the service user might do or say that has not been predicted in advance. This then involves a delicate balance between complexity and functionality. The Clinician User Interface is a bespoke piece of software, with only the character preview utilising Unity3D.

The character controller subsystem enables the manipulation of the emotions portrayed and utterances used by virtual characters. In Figure 4-4 the driver from the scenario is displayed on the right hand side of the screen, providing feedback to the clinician on what emotions are being displayed. On the left-hand side are the controls used to

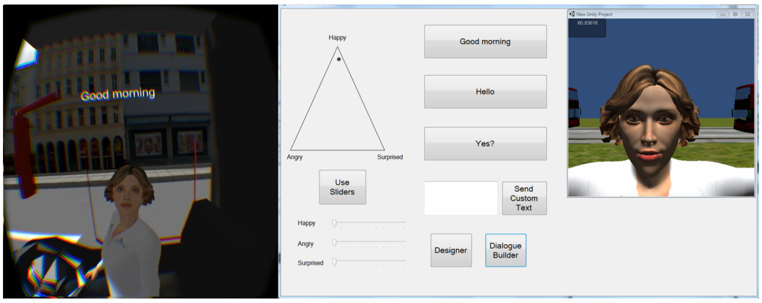

Figure 4-4:
Clinician interface

alter the character's appearance. The prototype features two such controls: the control triangle (top) and sliders (bottom) for continuous and discrete adjustment respectively. The character in the environment will display the same expression to the user.

4.5 Informal Feedback

The prototype was demonstrated to the clinical team to gather feedback on usability and discuss design ideas. The following are informal notes made in response to feedback:

- The graphical fidelity of the environment received mixed feedback.
- The environment itself felt empty, with only a single character and little ambient activity to distract users.
- Emotions portrayed by the character were unconvincing and difficult to both detect and read. Clearer emotions are needed if the system is to be used by people with socio-cognitive impairments.
- Real voices were more desirable than computer-generated to facilitate socio-cognition.
- The dialogue system was slow to use, especially when unpredicted responses (e.g. statement: "I'd like a ticket please", response: "No") were used.
- The clinician should be able to see the user's view inside the VR environment.
- Scenarios could be made to increase in difficulty, such as adding ambient noise or difficult characters.
- Financial transactions felt immersion-breaking, as there was no physical exchange of money.

- Being able to look/move around or stand would feel more immersive.
- Eye gaze tracking was of interest, with clinicians interested in where somebody was looking or whether they were staring.
- Data from the environment could be tracked over time (e.g. to determine if someone is stuck).

This feedback contributes to our understanding of how virtual reality environments can be designed to support activities in clinical rehabilitation.

There were also technical constraints to the Virtual Bus Stop:

- Handing over money was implied through dialogue (e.g. "Here you go") rather than any interaction that would map onto a real world financial exchange.
- Users were required to sit down in order for headset tracking to work. This meant that movement was controlled by keyboard.
- The headset cable was also short and frequently got in the way of users.
- Movement was further restricted technically by not allowing users to move until the bus had stopped, in case they stepped into the road.
- After paying for a bus ticket, users should pick a seat. We wanted there to be a cognitive decision involved: does the person choose to sit by themselves or do they sit next to the attractive individual? With the constraint to sitting down and there being lots of chairs to choose from, this was not really practical.

4.6 Conclusion

We have used a prototype to validate ideas on how a VR system might contribute to a therapeutic activity to practice community access. Informal feedback from clinical professionals will feed into future design work, however we have also identified technical constraints that will need to be considered. This work has given us a starting point through which to converse with clinical professionals and to demonstrate the potential of VR.

Chapter 5

Clinical Assessment Frameworks for Community-based Behaviours

5.1 Introduction

This thesis is exploring how virtual reality technologies can support rehabilitation activities and deliver meaningful benefits to people involved with acquired brain injury rehabilitation. It sets out to achieve five objectives:

1. To explore the types of activities conducted in clinical practice for the rehabilitation of executive dysfunction, including their purpose, strengths and limitations.
2. To iteratively design and develop a virtual reality environment prototype that we expect to have meaningful use in a therapeutic programme by echoing aspects of clinical activities.
3. To determine the potential for a virtual reality environment to observe behaviours associated with executive functions in both neurotypical people and those with acquired brain injuries.
4. To gather feedback on the utility and validity of a virtual reality environment from clinical professionals.
5. To present design guidelines for the future development of virtual reality environments for acquired brain injuries.

Our work so far has been in pursuit of the first two objectives, where our exploration of activities has centred on theory as described in literature and on how this translates to clinical practice, and our design and development of a prototype has built upon a specific activity. In Chapter 3 we identified interaction around an everyday activity – getting onto a bus – as being a starting point for our research. This activity had a meaningful clinical benefit: to enable service users to practice using public transport to improve community access. This led to the development of a prototype, the Virtual Bus Stop as reported in Chapter 4, to explore an initial conceptual design, and to provide a platform through which HCI practitioners and clinical neuropsychologists can communicate and validate ideas contributing to a mutual goal.

This approach is an integral part of HCI design work, in which we acknowledge the extent of our knowledge of our target domain and embrace the limits of our understanding. We seek relevant expertise to fill in the gaps and engage in collaborative conversations with domain experts to further our shared understanding. It is reflective of the integrative and multidisciplinary nature of clinical rehabilitation, in which professionals bring specialist knowledge to a team and collaborate to devise rehabilitation activities towards shared goals (Zarbo et al., 2016). This same approach, where clinicians and HCI researchers bring domain-specific knowledge to further each other's understanding, is essential to develop a meaningful and usable system for rehabilitation (Rizzo et al., 2004; Rizzo and Koenig, 2017).

Our exploration of rehabilitation activities has so far been informed by documented information about existing clinical practice and visits to Brain Injury Rehabilitation Trust (BIRT) services. We have followed a cycle of sourcing information from relevant literature to identify concepts that appear to have importance in clinical settings. For instance, that roleplaying exercises might be prescribed as part of a programme to rebuild socio-cognitive skills (Goll and Hawley, 1989, pp.147-149). Such information is useful for framing our initial understanding of the problem, but it has limitations. Literature may describe recommended or theoretical approaches to rehabilitation which have been adapted or replaced altogether in practice. It may describe techniques not widely used, or which have become outdated. In our cycle, we have followed up this information through visits to BIRT services and learning about the day-to-day operations of rehabilitation.

Our dialogue with clinical professionals has therefore sought to verify and refine our initial understanding of acquired brain injury (ABI) rehabilitation gained from these literary sources. Through engagement activities, key ideas have been drawn out in order to set a valid direction for this research. Anecdotal evidence has been drawn upon to affirm information and provide context such that it can be treated as knowledge. For instance, we learned that the roleplaying exercises described in literature have a meaningful place in clinical practice, and that they are used to prepare for community-based activities, but also that they have limitations not recognised in literature. To this end, the informal passing of knowledge between clinical professionals and HCI researchers has been effective, but carries an inherent risk of being open to interpretation on both ends and painting an incomplete picture of contemporary clinical rehabilitation practice.

For our part as HCI researchers we are naïve to the complexities of clinical activities in ABI rehabilitation, and even the most thoroughly described rehabilitation session cannot be accurately envisioned without first-hand experience. This dilemma is exacerbated by the involvement of impaired individuals, whose behaviour and nuances can surely only be fully realised through direct interaction with them. Through our visits to BIRT services (see Chapter 3) we encountered service users for only brief periods of time, rarely conversing for longer than a greeting, and we were in a clinical and supervised environment. Then we must consider the experts advising us on clinical practice, whose recollections, revelations and language are aided but constrained by their experience. A habitual action, or what may be presumed as common knowledge, might well be omitted yet hold significant in a therapeutic activity.

Consequently, we require first-hand observations to assist us in understanding the context in which a virtual reality environment might be used. This is a core tenet of HCI research and includes talking to end-users – the clinical professionals responsible for administering therapeutic activities and service users participating in these activities – as well as higher level stakeholders – the consultants responsible for prescribing them.

In Chapter 3, clinicians identified two challenges to their work of restoring independent living skills in community-based settings:

1. Accessing the community. Being able to use public transport to access amenities located away from the rehabilitation centre.
2. Behaviour in the community. The socio-cognitive and functional behaviours that are exhibited whilst engaging in activities in community settings, such as in a shop or street.

Although our early design and development work has helped us to test technical ideas and validate our thinking with clinical professionals, we found there to be practical limitations to a VR implementation of boarding public transport. We agreed with clinicians that we should explore how community-based behaviour is assessed to take our ideas further. To facilitate this goal, we were invited to have first-hand experience of behavioural assessments used in clinical practice, including observing a service user on a community-based assessment.

In this chapter we look to understand the purpose of behavioural assessments for community-based activities, how this is performed in current clinical practice, and the strengths and limitations of this practice. The purpose is to further explore and understand the activities used in clinical practice for the rehabilitation of executive dysfunction, such that their salient properties can inform the design of a VR prototype that has meaningful use in a therapeutic programme. We start by outlining why behavioural assessment is important, using clinical input as guidance, before reporting on clinical frameworks that we were introduced to for behavioural assessment. Analysis of a test battery and an ethnographically inspired observation directly contribute to our understanding of the types of activities that someone with a brain injury might undertake. This includes the purpose of the specific therapeutic activity, the procedure and settings for conducting it, the insight it is designed to facilitate, and how it is assessed. All of these feed into the design of a virtual environment that could be integrated into a therapeutic programme and deliver meaningful benefits for service users and clinicians.

It should be acknowledged that the clinical assessments described in this chapter are powerful neuropsychological assessment tools. They are closely guarded by clinical professionals who are responsible for administering, interpreting and reporting appropriate assessments, and making trained determinations about a given service user's capabilities and rehabilitation progress. As such, they should not be administered without appropriate guidance.

5.2 Clinical Benefit of Behavioural Assessment

Brain Injury Rehabilitation Trust service users exist who clinicians are willing to grant unescorted community access to. These are people who are equipped with appropriate strategies to manage their challenging behaviour or impairments, and who clinicians have confidence are capable of safely navigating the complexities of a community environment such as a supermarket or town.

However, many service users at BIRT do not yet have these strategies and skills to perform everyday activities in the community. They might need to go out and practice being in a shop or walking around an urban area. Clinicians need to be able to observe service users exercising socio-cognitive and functional skills in these real live environments in order to have assurances that the person will be safe in these settings.

A key example of this is Dan, a BIRT service user interviewed and followed on the BBC documentary “Louis Theroux – A Different Brain” (BBC, 2016). Dan was 10 years post-traumatic brain injury (TBI) and had been in a BIRT service for 2 years. He was shown to be high functioning, able to independently order and pay for food in a café, and had moved into one of BIRT’s self-contained flats to practice his independent living skills. He had previously been given unescorted community access but then got involved with the wrong sort of people; Dan got involved with drugs and gave away his personal belongings. Dan also had a tendency towards practical jokes which were described by clinicians as going over the top, occasionally causing alarm in support workers.

Staff would like to offer Dan unescorted community access again, but they feel that he is vulnerable in the community with potential drug and alcohol influences. The consultant neuropsychologist explained the reasoning:

> *“I’d be concerned that things would start to slide... Dan would start making associations with people that were selling drugs and that Dan would start kindof spending all his money on drugs and alcohol, and whilst he was under the influence... he would then engage in behaviours that might actually put him in trouble... In the past, that’s some of the behaviour [that he exhibited]” (BBC, 2016).*

Dan was shown to be frustrated at having to stay in the BIRT service. It was acknowledged that Dan had the abilities to live independently, but that the consultant needed “evidence” that he could go out into the community and not be at risk.

For service users such as Dan, clinicians need a way of evaluating behaviour in the community and exposing service users to the risk factors that they might encounter when living independently.

Challenging Behaviour

Going out into the community is not as simple as being escorted by a clinician or support worker. For some service users, even escorted community access is a risk. Challenging behaviour might be contained in familiar clinical settings where it has been learned, but then re-appear when out in an unfamiliar environment or with the stimuli of a busy community setting.

Challenging behaviour in a rehabilitation centre can also preclude community-based activities. During an observed clinical team meeting (CTM), clinicians discussed “Phil” in this context. Despite having allotted time for community activities, Phil had not gone out that week. He had been showing good behaviour but consistently demonstrated poor/challenging behaviour directly before leaving, including raising his voice and punching someone. Consequently, Phil's community access had been withheld and the activities cancelled. Clinicians talked through his rehabilitation goals for the week, which had also consisted of community-based activities: to go to the leisure centre, to go shopping, and to practice finding a route around town. None of these goals had been met because Phil was not allowed out after his behavioural outbursts, due to risk in the community.

The consultant neuropsychologist highlighted this case to the visiting researcher, commenting that this was someone who could benefit from a virtual reality analogue of community activities. The consultant pointed out that Phil, like many other service users, were often distracted by smoking, gambling or drinking habits and that they needed to practice inhibiting these impulses towards frustrations, distractions and temptations.

There is also the risk of challenging behaviour taking place in the community, with staff concerned that verbal or physical aggression or inappropriate behaviour might place the service user or member of the public at risk.

In another CTM, clinicians talked about a service user "Peter" who had been exhibiting good behaviour and going out into the community. However, an occupational therapist noted that he had been expressing some racist views around the rehabilitation centre. Consequently, staff were concerned about taking him out into the community, for fear that he might openly express views and start a confrontation.

Road Safety

Road safety was also an area of concern discussed by some clinicians. This is a functional skill that requires planning, awareness, persistence and inhibition, and can be dangerous to practice even when supervised. In addition to this, challenging behaviour can manifest as stepping into traffic in order to cause harm. Clinicians need reassurance that service users are going to be safe in the community and to provide appropriate settings for practice and assessment of road safety skills.

Anxiety

Service users can spend a lot of time in rehabilitation settings and become anxious about returning to a community environment with people they are unfamiliar with. Some may also have troubling memories of their time in the community, especially when violence might have been a factor in their injury or if they have had psychologically traumatic experiences. A service user "Terry", who we introduced in Section 3.5.1, was discussed in a CTM with such anxiety. Terry was new to a BIRT service but several years post-injury, and had previously exhibited aggressive behaviour and spent time in prison. When describing activities for Terry in the local community, clinicians indicated that he was capable of performing community-based activities such as route-finding, but that he was anxious of the area (perceiving it as dangerous) rather than his own behaviour.

Similar to community access, services users need opportunities to practice activities that cause them anxiety. In this case, to go out into an area of the community and practice being alone or handling difficult situations.

Insight

Insight is also important, where service users might feel that they will perform well in the community based upon their experiences in a rehabilitation centre. For example, BIRT service user Dan was shown being escorted into the community by an assistant psychologist, who explained how her presence facilitates insight:

> *"The idea is that Dan has such a lovable, likeable personality. But you can be a little bit over the top with your jokes, and it sometimes might put him in a bit of an awkward situation with the public. So we let him do his thing and offer him a little bit of feedback." (BBC, 2016).*

Having this opportunity to go out not only helps clinicians to assess behaviour and give feedback, but for the service user themselves to exercise self-awareness and see how they perform in functional settings.

Summary

It is important for service users to have the opportunity to practice everyday living skills in functionally relevant community settings, where they can exercise their independent skillset and behavioural strategies. From a clinician's perspective, this is to understand how service users behave in real world settings and to assess their capacity to live independently and safely. From a service user perspective, community activities serve as exposure and preparation to life outside a rehabilitation centre, allowing them to practice being in these settings.

During our visits to BIRT, clinical professionals demonstrated to us the therapeutic

Component	**Executive function**
Initiation and drive	Starting behaviour
Response inhibition	Stopping behaviour
Task persistence	Maintaining behaviour
Organisation	Sequencing and timing behaviour
Generative thinking	Creativity, fluency, problem solving skills
Awareness	Self-evaluation and insight

Table 5.1: Clinical model of executive functions, adapted from Sohlberg and Mateer (2001, p.237)

frameworks used to assess behaviour. In this chapter we are seeking to understand the procedures for running these assessments, their strengths and drawbacks.

5.3 Centre-Based Behavioural Assessments

The clinical assessment of behaviour is key for the extent of executive dysfunction to be determined, and for rehabilitation to be successfully tailored towards the individual (Sohlberg and Mateer, 2001; Wood and Bigler, 2017). Executive dysfunction, as an umbrella term for impairments to the processes that regulate behaviour, is a broad diagnosis and clinicians require a variety of assessment frameworks in their toolkit to observe problem behaviours, expose their cognitive roots, and prescribe rehabilitation activities to remediate them. Clinical professionals from BIRT introduced us to some of the assessments used in contemporary practice to understand behaviour. These assessments are carried out within a rehabilitation centre as part of a BIRT service. We are using the term “centre-based” to distinguish these from the “community-based” assessments we talk about later in this chapter.

Multiple theories have been proposed to categorise the brain’s regulation of behaviour into discrete components (Luria et al., 1966; Stuss and Benson, 1986; Keil and Kaszniak, 2002). As discussed in Chapter 3, Sohlberg and Mateer’s (2001, p.236; Table 5.1) clinical model of executive functions frames our research because of its emphasis on the clinical meaning of components, and its use by BIRT clinicians. Each component describes an essential aspect of neurotypical cognitive control that may be disrupted by an acquired brain injury

Considering executive dysfunction as impairments to any one or more of these components enables clinical professionals to more precisely describe what deficiencies might exist following an acquired brain injury.

5.3.1 Standard neuropsychological tests

Standard neuropsychological tests exist that seek to test one or more of these executive components. These tests may assess inhibition, working memory, attention, planning and self-monitoring (Sohlberg and Mateer, 2001; Wood and Bigler, 2017). They are typically singular-task tests, where a service user is given instructions to perform a task and is clear of distractions or the need to think beyond the task-in-hand. The Wisconsin Card Sorting Test (Heaton, 1981) and Stroop Colour and Word Test (Stroop Test; Stroop, 1935) are frequently described in literature and have been often mentioned in BIRT practice.

The Stroop Test was demonstrated to us in an early service visit, where a clinician administered it and the visiting researcher was a subject. It was demonstrated in a consultant neuropsychologist's office with standard office furnishings.

In the Stroop Test, the subject is shown a series of words, each of them the name of a colour. The text is printed in different colours. For example, the text "Green" might be coloured red. The test starts off without colour variation (e.g. text "Red" coloured red) to get a baseline measurement, then introduces varied colours. This measures the cognitive ability to inhibit a response (inhibiting the word recognition cognitive process) and attention over time (continuing to follow the rules throughout the task). We were also shown a variation involving rule shifts, where the subject was told to switch to reading the words instead of naming colours. This measures cognitive flexibility – a subcategorisation of generative thinking – and inhibition/initiation to stop and start following different rulesets.

Such neuropsychological tests can be useful as early measures of executive dysfunction, and can assist clinicians in highlighting components of executive functioning that may be impaired following a brain injury. However, their sensitivity to executive dysfunction is variable, and it has been documented that some people with obvious executive impairments can perform well on these tests (Sohlberg and Mateer, 2001; Wilson et al., 1996; Eslinger and Damasio, 1985; Shallice and Burgess, 1991). Furthermore, these tests are not concerned with the challenges of independent living skills.

5.3.2 Behavioural Assessment of Dysexecutive Syndrome (BADS)

Standard neuropsychological tests are considered poor predictors of everyday life skills (Sohlberg and Mateer, 2001; Wilson et al., 1996). In order to assess these skills, standardised tests should be designed to be more like real life tasks that might be faced by people living independently in the community, and that map directly to everyday behaviours (Wilson et al., 1996).

The Behavioural Assessment of the Dysexecutive Syndrome (BADS; Wilson et al., 1996) is a test battery used by BIRT to assess service users in functionally relevant scenarios, such that observed behaviours can predict performance on everyday life skills. It consists of seven assessments that are administered separately, either at different times or consecutively. Below we list the tests with summarised instructions.

1. Rule Shift Test – (1) Follow the rules as cards are turned. (2) Follow a new set of rules.
2. Key Search Test – Draw a path through a field to maximise chances of finding a key.
3. Zoo Map Test – (1) Plan a route through the zoo. (2) Plan a route with ordering requirements.
4. Action Program Test – Get a cork out of a tube using a jug of water and a beaker.
5. Temporal Judgement Test – Estimate how long activities/events might take.
6. Modified Six Elements Test – Here are tasks divided into six groups. Attempt one task from each group within a time limit.
7. Dysexecutive Questionnaire – Self-reporting questionnaire on executive tasks.

Before each test, the clinician reads the instructions out loud, or asks the service user to read them. The service user is asked to confirm that they understand what they need to do. During each test, the clinician may speak to announce a change of rule, to seek clarification, or to prompt the service user. The clinician also announces when the test is over.

Here we briefly describe each of these tests, including their purpose and an outline for scoring – the quantifying of assessment results to be interpreted in order to make inferences about a person's behaviour and skills. It should be noted that deliberately vague details were provided to us on scoring, and are similarly vague described in Wilson et al. (1996) to protect the assessment. Clinical expertise is needed to deploy and interpret results.

As before, the BADS was demonstrated to us by a BIRT clinician administering the test, and the researcher sitting as a subject. The BADS was administered in a private therapy room within a BIRT service, with just a desk and chairs and limited other furnishings.

Rule Shift Test

The Rule Shift Test is an evaluation of a person's ability to switch between different sets of rules, applied at different times. The test is administered using a set of red and black playing cards shown consecutively and begins with a simple instruction: as each card is shown, the person should say "yes" to red cards and "no" to black cards. After a number of cards are shown, a new rule is introduced: say "yes" if the newly shown card is the same colour as the previous one, otherwise say "no". This is quite similar to the adapted Stroop Test shown to us, in which a rule change is administered.

It is a measure of cognitive flexibility – a subcategorisation of generative thinking –, persistence, inhibition and initiation, whereby the brain needs to cease attempting to following one set of rules and rapidly transition to a new set. The Rule Shift is also executive in that it requires users to switch out of a routine behaviour and adapt to a novel behaviour, so it could be said to invoke the Supervisory Attentional System to trigger a change in behaviours (see section 2.3; Norman and Shallice, 1980).

At the end of the test, the number of errors committed (when the incorrect response was given) and the time spent on each part of the test (first rule and second rule) are recorded. The score is a function of these measures.

Key Search Test

An element of roleplaying can be found within some of the BADS tests. In the Key Search Test, the service user is asked to imagine that they have lost their keys somewhere in a rectangular field. They are presented with a rectangle on a piece of paper and are instructed to draw the path they would take through the "field" to maximise their chances of finding the keys. This is a measure of organisation and planning, generative thinking and awareness; the user needs to self-monitor and be critical of their plan, adapting as needed to cover the space effectively.

The percentage of the field covered and effectiveness of the search pattern (details undisclosed but measured through analysis of the route taken), and time spent are recorded as performance of this test, with the score being of a function of these variables. This is not a unique response problem, as many different approaches could be taken to satisfactorily search the field. The search pattern drawn can be used to infer more about the nature and severity of an impairment; for example, a psychologist might analyse a search pattern that only takes up half of the field, or one that does not stay within the confines of the field. Further details were not disclosed to us, but this strikes us as an interesting characteristic of this test.

The Key Search Test is also reflective of a scenario that we might expect someone to face in a real world community setting, where they need to cover an area effectively for some purpose.

Zoo Map Test

Another roleplaying task is for the service user to suppose that they are planning out a trip to the zoo, in a measure of planning and generative thinking. The user is given a map of the zoo and a series of places to visit. In addition, there are some rules to adhere to, such as not revisiting the same place twice, avoiding certain paths, and so on. Once this task had been completed, it is administered again with additional rules around ordering. For instance, that the elephants need to be visited before the penguins. In both tasks, the desired path through the zoo should be drawn on the map.

The planning and implementation of sequential tasks is key to the Zoo Map Test. It is plausible that a person might attempt to draw a path one step at a time, without looking at the task in full and considering all requirements ahead of time. This might lead to inefficient paths, or those that break rules; we might conceive of a scenario where a client works through every step in the task, drawing out a path through the zoo, before reading a final step: "do not use the same path more than once". This inability to read and plan ahead could be costly within the task and could even cause some frustration; how a service user then responds to this frustration may be of interest to a clinician. The complexity can also be scaled, such that the rules or ordering might be made more difficult for some service users or on different attempts of the test.

It is easy to imagine how this test might relate to independent living settings. Although the constraints of not using a path more than once are a bit farfetched in the real world, the act of planning a trip around a town or shopping mall and needing to go to a series of shops in order is a plausible challenge.

The number of steps completed successfully, the errors made, time spent planning and time spent completing the tasks are recorded and contribute to the score. Splitting the time spent into planning and completing allows clinicians to make inferences about someone's ability to plan ahead versus jumping into a task without preparation.

Action Program Test

The Action Program Test is a classic problem-solving task, measuring the ability to solve a problem through sequential interdependent steps. There are several variants to this test, but the version administered to the researcher used a jar of water and a long cylindrical tube on a tray. A cork was placed in the bottom of the tube, and next to the tray was a small beaker. The instruction given to us was to retrieve the cork from the bottom of the tube, without moving any objects on the tray. A correct response would be to pick up the beaker, fill it with water from the jar, and pour water into the tube until the cork floats to the top. In other variants, a metal rod – not long enough to reach the cork – might be provided, as well as a lid on the beaker that cannot be touched with hands (Wilson et al., 1996; Canali et al., 2007).

Suggestions to the service user can be provided once every two minutes, which may help to further describe the nature of their impairments. For instance, someone may successfully pour water into the tube, but get stuck if there's not enough water to float the cork to the top, and need a prompt to repeat the action. This information can then be interpreted by a neuropsychologist to infer more about the person's impairments. The score for this test is a simple count of the number of unprompted steps to complete the task.

The interdependent steps required in this task are similar to other functional activities that we might imagine in residential or community settings. For example, putting water into a kettle is necessary before boiling it; sending a letter involves buying a stamp from a post office before applying and posting it.

Temporal Judgement Test

The Temporal Judgement Test is a measure of a person's planning ability, specifically temporal estimation. It requires calling upon prior experiences and knowledge, and reframing information to suit a current problem. A series of questions are asked that relate to real life events, and the service user needs to estimate a block of time associated with them. For example:

- How long does a check-up at the dentist take?
- How long does it take for an experienced cleaner to clean the windows of a medium-sized house?
- How long does a dog live?

The goal in answering these questions is not necessarily to get them correct; even neurotypical people might struggle to accurately determine how long a window-cleaning job would take. What matters in this test is a sensible estimation of time that uses the application of prior knowledge. An hour might be a reasonable estimation of window cleaning, whereas a month would be clearly wrong. The number of correct estimates is recorded and scored. Wilson et al. (1996) note that impaired temporal judgement is a predictor of executive dysfunction.

Modified Six Elements Test (MSET)

The Modified Six Elements Test (MSET) measures multiple components of executive functioning through attention, scheduling and memory challenges. Three different types of task, divided into two parts each for a total of six elements, are presented on cards. The types shown to us were event narration (tell a story about the images on the cards), a naming test (name the objects on the cards), and arithmetic. Other tasks, such as copying geometric figures, may be used (Canali et al., 2007). Further adaptations have been proposed in order to account for language deficits, such as a sorting task in place of event narration (Bertens et al., 2014). The instructions are to work through as many cards as possible in ten minutes, but to attempt something from all six elements during that time. The service user cannot go directly between two elements of the same type. For example, having completed an arithmetic test, they need to do either an event narration or naming test before returning to arithmetic.

The service user must exercise self-awareness to monitor their performance and regulate their behaviour, setting themselves ample time to attempt each of the subtasks. This might be undesired from their perspective, as they might prefer some tasks over others; wanting to put off the arithmetic problems might be an example of this. It also requires rapid task switching, which is further stressed by the restriction to change element type. The number of cards attempted, the time taken and number of errors are recorded. The score is calculated as a function of these.

Dysexecutive Questionnaire

The final component of the BADS is the Dysexecutive Questionnaire, which is described in literature (Wilson et al., 1996) but was not demonstrated to us. The questionnaire asks people to self-rate themselves in a variety of executive contexts, such as how impulsive they are and distractibility. The Dysexecutive Questionnaire is completed by both the service user and a family member, friend or carer who knows them well. The absence of the latter is why this was not run with the visiting researcher.

Scoring is based on how people rate themselves, with a higher score indicating greater executive dysfunction. A second “insight” score is generated by comparing the scores between the service user’s questionnaire and their family member, friend or carer’s questionnaire. If these differ, it may predict problems with insight that impede the acknowledgement of impairments and motivation to engage in rehabilitation.

5.3.3 Scoring and Reporting the BADS

For each test within the BADS, we have briefly detailed the procedure for conducting it and how the behaviours used to attempt it expose elements of executive functioning. We have briefly included the protocol for scoring individual tests. As previously acknowledged, any ambiguity in scoring is deliberate. The BADS is a potent neuropsychological assessment tool and its precise implementation is somewhat guarded by clinical professionals. Literature provides some detail on scoring (Wilson et al., 1996; Canali et al., 2007; Bertens et al., 2014), however since such detail was not communicated to us by BIRT clinicians we cannot say with confidence precisely how scoring is performed.

What we can say from the information given to us, backed up in literature, is that there are measures of interest to clinical professionals recorded by the BADS for scoring purposes:

- The number of errors made in tasks. This was common across many BADS tests.
- The time spent completing tasks. Likewise a commonly recorded measure was the time spent completing all tasks. In the Rule Shift Test this was separated into time taken to complete tasks for each rule.
- The time spent planning for tasks. In the Zoo Map Test the planning time was recorded, giving an idea of whether someone took time to plan or jumped into the task.
- Properties of routes taken. Mostly applicable to the Key Search Test, where clinicians record the routes drawn to make inferences about planning and generative thinking from route “efficiency”. This also applies to the Zoo Map Test, where a path through the zoo can be analysed.
- Accuracy of temporal estimation. Most notably covered by the Temporal Judgement Test, but also highly relevant to the MSET where service users must allocate time to complete all tasks within 10 minutes.
- Reliance on prompting. The number of prompts used to complete a functional task in the Action Program Test, and the point(s) at which prompts were needed.
- Levels of insight and self-reporting. The Dysexecutive Questionnaire is concerned with how aware a person is of their impairments, and self-reporting is used as a

mechanism to do this. There is also opportunity for this across all tests where service users might be asked how they feel they had performed.

The BADS was demonstrated to us using the same materials as if it were being administered to a BIRT service user (minus the Dysexecutive Questionnaire, since there were no relatives, friends or carers to compare against). These included appropriate cards (Rule Shift, MSET), beakers/tubes (Action Program), and paper to draw on (Zoo Map, Key Search). Performance in each test was logged by the clinician administering/demonstrating the assessment, who kept the used papers for the Zoo Map and Key Search tests, used audio tape recordings for the MSET, and by making hand-written notes of observations.

The output of the BADS is therefore a series of hand-written observations, audio logs and attempts drawn on paper. In some cases, this will include recording instances of interesting behaviour through the antecedents, behaviour and consequences (ABC) model or other forms. The administering clinician will use these outputs and the scoring protocols for the BADS to make relevant remarks on the service user's performance and behaviour. This involves transcribing notes or scanning in documents, interpreting test results, and adding these to a service user's clinical file. These then contribute to clinical team meetings to track progress and inform rehabilitation goals.

Expert judgement, currently recorded as hand-written notes, are therefore integral to the reporting process; they take information about behaviour and performance in behavioural assessments and contribute to the broader picture required to track someone's progress through rehabilitation. This reporting is vital for the person with the brain injury, their clinical team, friends and family, and even insurers or financial sponsors who are concerned with tracking progress. However, comprehensive notes require the divided attention of a clinician to take during a therapeutic session. Specific utterances or actions might be forgotten when writing up later, or missed altogether due to multitasking. This can be exacerbated when recording behaviours, antecedents and consequences when such detail might not be easy to recall amidst running a test.

It is apparent that there is an overhead incurred with the reliance of hand-written notes and observations of tests. For example, counting up how many cards have been completed in the MSET. Even the Zoo Map and Key Search tests, which are conducted purely by drawing paths on paper, require some nominal time to scan in.

5.4 Research Implications of the BADS

The Behavioural Assessment of the Dysexecutive Syndrome (BADS) battery highlights some considerations for our research.

5.4.1 Behaviours of Clinical Significance

The BADS sets out to deliver tests that reflect real world tasks and map onto everyday behaviours. Here we summarise the everyday behaviours that are assessed by the BADS, and give examples of how these represent the community-based activities that this chapter is concerned with.

- Rule Shift Test – Inhibiting an existing behaviour and triggering a novel behaviour (e.g. stop walking when you find the post office and go in).
- Key Search Test – Planning out an efficient route to meet an objective (e.g. walk around town to search for a supermarket).
- Zoo Map Test - Planning a journey around a series of stops (e.g. find a supermarket before it closes; visit a post office before a postbox; do not use a route twice).
- Action Program Test – A functional problem-solving task with interdependent steps, similar to many everyday activities (e.g. boiling water in a kettle; sending a letter).
- Temporal Judgement Test – A necessary component to planning. (e.g. estimating the time to make a tea, or to walk to a bus stop to catch the next bus).
- Modified Six Elements Test – Multi-tasking between tasks that are different in nature and timekeeping. (e.g. multi-tasking between counting up the price of groceries and reading a shopping list; leaving yourself enough time to buy a train ticket before the train arrives).
- Dysexecutive Questionnaire – Less applicable to real world behaviours, but generally facilitating insight and awareness of deficits (e.g. "I know that I struggle to remember and follow a plan, I'll write out a to-do list before I go shopping").

The implication for our research is that these are examples of behaviours have clinical significance when assessing a person's behaviour. We can apply each of these behaviours to functionally relevant real world activities in the community. When looking at how technology might support behavioural assessment for community activities, these are examples of behaviours that we should consider.

5.4.2 Data for Clinical Interpretation

Further considerations relate to the recording and scoring of the behaviours being assessed. Our analysis of the BADS has identified seven measures of behaviour (gathered for scoring purposes) that are of clinical interest. These are currently recorded through hand-written notes and other manual forms of observation. Having detailed these previously, we shall summarise them here:

- The number of errors made in tasks.
- The time spent completing tasks/sub-tasks.
- The time spent planning for tasks.
- Properties of routes taken.
- Accuracy of temporal estimation.
- Reliance on prompting.
- Levels of insight through self-reporting.

This gives us an idea of the type of data that is important to clinicians. This thesis has sought to understand the fundamentals of brain injury rehabilitation and the meaning behind rehabilitation activities, but we do not know how clinicians interpret this data for the purpose of clinical decision-making. Since we are following an integrative multidisciplinary approach, we must acknowledge that the role of the clinician cannot be replaced and that clinical input is required to interpret this data. We can only facilitate the recording of this data to be used appropriately by trained professionals. Any technology to support behavioural assessment should therefore facilitate the observation and recording of these measures.

5.4.3 Limitations

Standard neuropsychological tests can be designed to challenge components of executive functioning (Heaton, 1981; Stroop, 1935), however these typically involve abstract problem solving that offer little to predict how deficits impact upon everyday activities in independent living. There have been attempts to create more specialised tests that mimic real life tasks that could be countered by people living independently in the community (Wood and Bigler, 2017). The Behavioural Assessment of Dysexecutive Syndrome (BADS) test battery aims for relevance to real world tasks; this might be through roleplaying out a community-based setting or through more generalised skills that map onto a broader range of independent activities (e.g. estimating and allocating appropriate time to do something, such as catching a bus or posting a letter). Such tests afford a greater potential for clinical insight into a person's ability to safely and independently perform everyday tasks.

There are, however, limitations to the BADS and similar centre-based behavioural assessments. Although widely used and valued for its ease of use and speed to deploy in a centre-based setting, the BADS has also been observed to lack sensitivity to some people living with executive dysfunction, particularly high-functioning individuals (Wood and Bigler, 2017; Sohlberg and Mateer, 2001, p.113). Assessments such as the BADS may be completed successfully by someone with neurobehavioural symptoms, but who may still struggle with activities of daily living in the community (Jessup, 2018; Shallice and Burgess, 1991).

This is because the impact of executive dysfunction on behaviour is most observable in activities that require self-regulation and awareness of task-related behaviour, the organisation of multiple and competing tasks and information, and the ability to block out distractions and maintain attention over time(Sohlberg and Mateer, 2001). Here we note the limitations of the BADS to facilitate successful observation of executive behaviours in everyday community-based activities, the concern for this chapter.

Relevance for Community-Based Activities

We have shown how BADS tests represented the community-based activities that this chapter is concerned with. For example, the Action Program test uses the interdependent steps that might be found in posting a letter, or the Temporal Judgement Test requires estimation of events that may be required to plan out a shopping trip under time constraints. Despite this relevance to everyday activities, the BADS is an abstraction of everyday activities and is performed in a rehabilitation centre environment. It does not support assessment of people actively engaged in independent everyday tasks in a community setting (Wood and Bigler, 2017).

Tests such as the BADS have applicability to functional tasks, such as estimating time or route-planning. However, neurobehavioural disability presents both socio-cognitive and functional challenges. Some of the clinical benefits of behavioural assessment we discussed in Section 5.2 rely on socio-cognitive skills. For example, if a service user is anxious about drawing suspicion from a member of the public, then having the opportunity to assess the service user's interactions with people would be a valuable component of behavioural assessment.

Self-regulation and Monitoring of Behaviour

Tests are highly structured and formalised scenarios, each with a defined starting and end point. In the BADS, service users are recipient to a degree of prompting on when to commence an activity, when to listen and consider the rules they are operating under, and when they have completed a task satisfactorily. The clinician is taking responsibility on managing the assessment, including when one task ends and another begins. In such situations, the clinician is assuming the role of the service user's executive control (Jessup, 2018; Torralva et al., 2012; Gioia and Isquith, 2004).

Service users need to monitor their progress on a task and the situations they are in, and adjust their behavioural responses to the task in hand. They also need to exercise initiation of tasks and switching between rulesets, rather than being prompted to do so.

Activity Duration

Executive dysfunction's impact on behaviour is most observable in tasks that require the maintenance of attention over time, where deficits to persistence and planning can inhibit progress towards goals (Sohlberg and Mateer, 2001). This is important as real world activities typically require people to maintain behaviours over long periods of time (Shallice and Burgess, 1991). Each test in the BADS and similar assessments takes place over a short period of time, usually less than 10 minutes, with a distinct pause between each task. Any lapse of attention towards the end of the period is regained by the clinician giving the next set of instructions and checking for understanding. Attention is only required across a short time, is supervised, and is highly directed towards the task at hand.

Organisation of Multiple Tasks and Information

Tests in centre-based assessments usually require focus on one or two tasks at a time. Information is delivered in chunks, with written instructions broken down and provided at the start of each task. Although there is some work in understanding the task instructions, much of the organisation is offloaded to the clinician. In the real world, people have to balance many different activities, each with their own set of subtasks, and pieces of information as they go about their daily lives (Shallice and Burgess, 1991).

They also have to prioritise and re-prioritise these on the fly. For example, imagine you are performing errands and are on your way to the supermarket, but also need to post a letter. If you walk past the post office, you may need to re-prioritise and go to the post office first. However, the closing times of the post office and supermarket may be of further consideration to prioritise these tasks. People in real world settings have to consider multiple tasks and information of competing priorities.

Distractions, Temptations and Frustrations

The ability to maintain task-related behaviour is an important consideration for executive dysfunction assessment (Sohlberg and Mateer, 2001). We have previously noted that centre-based assessments took place in rooms within the service when demonstrated to us. These assessments are designed to be administered in clinical settings, with limited distractions, frustrations or temptations to challenge our ability to focus on the task. In the real world we would look at an activity in the community and observe a plethora of visual and audio stimuli outside of the task being performed. Some of these might be challenging to people going about their daily business (e.g. loud traffic when trying to read a shopping list or have a conversation).

In Section 5.2 we reported that a consultant neuropsychologist had talked about the problem of addiction in many service users. Many had smoking, drinking or gambling habits that were exacerbated by their deficits to inhibition. For such people, distractions such as tobacconists or bookkeepers could present considerable challenges to focusing on tasks, but are these are not present in the centre.

Additionally, the temptations and frustrations inherent in social interactions is missing in the BADS. To predict safe and independent behaviour in the community, service users should be tasked with challenging social interactions that might require the inhibition of aggression in response to frustration, or the inhibition of inappropriate behaviour when faced with temptations.

Practice Effects

A final limitation is that tests take place in a controlled and invariable environment – both the Stroop Test and BADS were demonstrated to us in a room (office/therapy room respectively) within a BIRT service. The tasks generally remain the same across repeated assessments; some scaling is possible with some tests (e.g. the Zoo Map's route planning constraints) but this is limited. External stimuli are also limited due to the lab-like controlled setting; there were very little distractions or frustrations in these rooms other than the occasional sound of footsteps outside. This could lead to service users improving their performance across assessments purely through familiarity with the tasks, without any additional confounding factors that may place additional demands and thus maintain a challenge. This practice effect has been suspected with the BADS, where control subjects scored higher when repeating 6-12 months after their first attempt at the test battery; it should be noted that due to small sample sizes, low p-values and outlying data, the full extent of this practice effect was inconclusive (Wilson et al., 1998). Nevertheless, practice effects are recognised in assessments for executive dysfunction and should be considered when prescribing such tests and interpreting the results (Johnson et al., 1991; Rabbitt, 2004; Wood and Bigler, 2017).

Design Guidelines from Limitations

These limitations of the BADS provide us with design guidelines for technology that might be used to support the behavioural assessment of people with neurobehavioural symptoms arising from executive dysfunction. They are:

- It is insufficient to map tests onto real world activities. Observations should be of individuals going about real everyday activities in the community (Wood and Bigler, 2017).
- Assessments should incorporate socio-cognitive and functional elements.
- People need to be given room to exercise the regulation of task-related behaviour independently, without prompts or offloading.
- Behaviours need to be assessed over a sufficient period of time that impairments to executive control become observable.
- People should be assessed managing multiple pieces of information and tasks with competing priorities and demands.
- Assessments should include levels of distractions, temptations and frustrations that 1) challenges their individual compulsions and inhibitions and 2) challenges them in both a functional and socio-cognitive context.
- Assessments should vary enough in difficulty to mitigate the risk of practice effects.

5.4.4 Implications of BADS for Research

In this section we have outlined the research implications of our analysis of the Behavioural Assessment of the Dysexecutive Syndrome. We are exploring the potential for virtual reality technology to support the behavioural assessment of executive dysfunction, and our findings contribute to this goal.

We have established a list of behaviours that have clinical significance and described how they relate to community-based activities. Technology should seek to facilitate the observation of these behaviours:

- Inhibiting an existing behaviour and triggering a novel behaviour (e.g. stop walking when you find the post office and go in).
- Planning out an efficient route to meet an objective (e.g. walk around town to search for a supermarket; plan to achieve multiple tasks in one location).
- Planning a journey around a series of constraints (e.g. find a supermarket before it closes; visit a post office before a postbox).
- Perform interdependent steps to complete an activity (e.g. buy a stamp before sending a letter).
- Estimating and managing time (e.g. estimating the amount of time needed to walk to a bus stop; managing time to stop shopping and get to the bus stop).
- Multi-tasking between tasks (e.g. multi-tasking between counting up the price of groceries and reading a shopping list).
- Exercising insight and self-awareness (e.g. “I know that I struggle to remember and follow a plan, I’ll write out a to-do list before I go shopping”).

We have also noted the types of data that appear to be of importance to clinicians looking to observe and interpret behaviour:

- The number of errors made in tasks.
- The time spent completing tasks/sub-tasks.
- The time spent planning for tasks.
- Properties of routes taken.
- Accuracy of temporal estimation.

- Reliance on prompting.
- Levels of insight through self-reporting

We also have design considerations for the design of a system to facilitate these behaviours and collect this data:

- It is insufficient to map tests onto real world activities. Observations should be of individuals going about real everyday activities in the community (Wood and Bigler, 2017).
- Assessments should incorporate socio-cognitive and functional elements.
- People need to be given room to exercise the regulation of task-related behaviour independently, without prompts or offloading.
- Behaviours need to be assessed over a sufficient period of time that impairments to executive control become observable.
- People should be assessed managing multiple pieces of information and tasks with competing priorities and demands.
- Assessments should include levels of distractions, temptations and frustrations that 1) challenges their individual compulsions and inhibitions and 2) challenges them in both a functional and socio-cognitive context.
- Assessments should vary enough in difficulty to mitigate the risk of practice effects.

In the next section we shall look at an example of a community-based assessment that demonstrates how clinicians currently seek to overcome these limitations and expose the behaviours identified above.

5.5 Observing the Multiple Errands Test

We have established the clinical need for assessments of behaviour in the rehabilitation of executive dysfunction. These should provide an ecologically valid setting for people to practice conducting everyday living skills in a community environment, to allow clinicians to observe behaviours, expose their cognitive roots and thus devise rehabilitation strategies. Attempts have been made to do this in a rehabilitation centre environment, such as with the Behavioural Assessment of Dysexecutive Syndrome test battery. However, such assessments have limitations. Understanding impairments to everyday living skills requires observing people performing activities in an everyday community-based setting (Wood and Bigler, 2017).

Consequently, assessments have been developed that take people out of the rehabilitation centre and into the community to practice independent living skills. To better understand how such assessments work in practice, we were invited to observe a BIRT service user undergoing a behavioural assessment called the Multiple Errands Test.

5.5.1 Background of the Multiple Errands Test

The Multiple Errands Test (MET) was developed by Shallice and Burgess (1991) to assess survivors of acquired brain injuries (specifically those incurred through trauma) beyond the neuropsychological tests we have previously described. Their reported motivation came from a patient reported by Eslinger and Damasio (1985), who scored well on psychometric tests but presented with severe difficulties performing everyday living activities, with vocational and family consequences. Shallice and Burgess supposed that these tests were not sensitive to the competing demands of everyday living activities, and that the presence of a clinician on whom executive control can be offloaded was counter to the purpose of the assessment.

The original MET was set in a pedestrianised shopping area and required participants to:

- Obtain information: e.g. what was the coldest place in Britain yesterday?
- Buy items: e.g. buy a brown loaf.
- Follow a set of rules: e.g. spend as little money as possible.

The assessment was designed to challenge the organisation of behaviours and goal setting across an extended period of time and in the face of conflicting tasks.

Shallice and Burgess evaluated the utility of the original MET using 3 traumatic brain injury (and frontal lobe damaged) patients who had performed generally well on psychometric tests, but whose injuries were causing a prolonged and significant impact on their lives. These participants were assessed with the MET against 10 control (neurotypical) subjects. Results indicated that the patients demonstrated impaired performance on the MET, being less efficient and making more mistakes than the controls. We will expand upon the scoring and implications of the MET later in this section. However, it is worth noting that performance on the MET is considered to be a strong predictor of a person's ability to independently perform tasks in a community setting (Sohlberg and Mateer, 2001; Jessup, 2018). A number of different versions of the MET have been produced for clinical use since its inception (Jessup, 2018).

5.5.2 Observation of a BIRT service user

We were invited to observe a Multiple Errands Test assessment with a service user at a BIRT rehabilitation service on a weekday morning. A single researcher attended the observation, and upon arrival met with an occupational therapist (OT) who provided a briefing on the service user to be assessed. The researcher had attended the BIRT service before and had been previously inducted to the centre. No safety concerns were raised by the OT.

“Adam” was a middle-aged male who had resided at the BIRT service for around 8 months at the time of assessment, and was occupying one of the self-contained flats at the service. Adam did not exhibit the challenging behaviour that was typically illustrated by users of that service, which was often described as aggression and inappropriate behaviour. The challenging aspect of Adam’s behaviour was a lack of activity and drive to perform chores, instead preferring to remain in the flat and watch television. His challenging behaviour therefore manifested in the concern that he was not proactive in looking after himself.

The OT said that Adam primarily experienced trouble with task initiation, motivation and planning. Although his social skills were considered to be good, he came across as apathetic in interaction. The OT also noted difficulties managing money and short-term amnesia; when asked whether a debrief of the MET would be carried out later, the OT responded that Adam would likely not remember it within a few hours.

Upon meeting Adam the researcher observed apathy and short responses to the OT’s queries. Throughout the visit Adam did not attempt to engage with the researcher; the OT commented that Adam was typically interacted with by women in the service, and that he felt more comfortable interacting with them. The observation was performed by a female OT, a female junior OT, and a male researcher.

MET Briefing

The MET took place at a retail park located a short drive away from the rehabilitation centre. It consisted of a number of shops bordering a car park. Figure 5-1 shows an overview of the retail park. Only shops entered by Adam and named on the task sheet are labelled. The names of the carpet shops were not noted on the day.

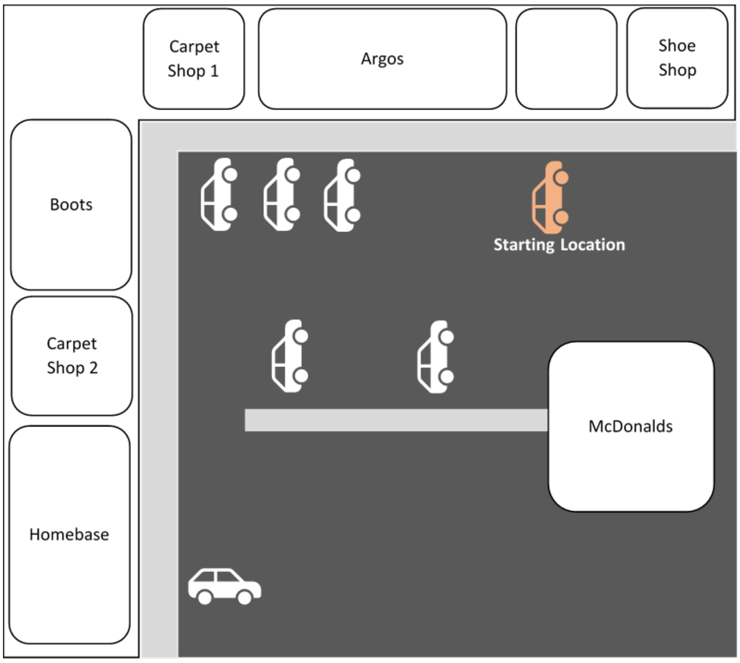

Figure 5-1: Map of the retail park used for the observed Multiple Errands Test

The journey to the retail park was made by car, and the OT briefed Adam in the car before we got out.

We requested permission to digitally record the session, but were unable to obtain consent prior to the assessment taking place. Instead, we were allowed to make handwritten notes and the retail park was re-visited after the assessment to take photographs.

Adam was asked whether he knew where he was and was correctly able to identify the retail park from the presence of Argos and other nearby shops. He was given an instruction sheet (the errands) and the OT read it aloud to him. We have included the instructions below:

In this exercise you should complete the following three tasks:

1. You should buy the following items:
    - A bottle of water
    - A packet of seeds
    - Shower gel
    - A hot drink of your choice
2. You should obtain the following information and write it in the space below:
    - What time does the carpet shop open on a Monday?
    - What time does McDonalds stop serving breakfast?
    - What two shops are next to Argos?
    - What time does the shoe shop close on Sunday?
3. You must meet me at the bench where we began the task 20 minutes after you have started the task and tell me the time.

    MEET THE PEOPLE OBSERVING YOU BACK AT THE AGREED BENCH AT THE END, AND TELL THEM YOU HAVE COMPLETED THE EXERCISE.

Whilst carrying out the exercise you must obey the following rules:

- You must carry out all of the tasks, but may do so in any order.
- Please remain in the area of .... retail park indicated at the beginning.
- You should spend no more than £10.
- No shop should be entered other than to buy something.

- You should not go back into a shop you have already been in.
- You should not purchase more than 2 items from any one shop.
- Try to complete the exercise within 45 minutes.
- Do not speak to the people observing you, unless it is part of the exercise.
- Please keep all receipts for all items purchased.

Note that “carpet shop” and “shoe shop” were written as above, and were not specific shop names. Spaces are included in part 2 as on the original instruction sheet, to leave room for answers to be written.

Although unspecified by the OT, the instructions correspond to the MET-Simplified Version (MET-SV, Alderman et al., 2003). By comparing the above instructions to the MET-SV, we have identified the following modifications:

- Tasks have been modified to reflect the availability of shops. Although a bottle of water could be obtained from three different shops in the park, a packet of seeds is a more niche request and would be less generalisable to other retail areas. Homebase at the retail park facilitated this task.
- Information gathering tasks have also been modified, with explicit reference to some shops. This corresponds to the type of instructions found in the real world (e.g. “Go to Tesco”). Of note, one errand was to find out what time the carpet shop opened on a Monday. The OT had chosen a carpet shop because, on her previous visit, the retail park only had a single carpet shop (Carpet Shop 1). By chance, Carpet Shop 2 had opened shortly before the observed assessment, but the OT had not realised until the assessment was underway. This points to the OT having freedom to modify the MET instructions to suit the shops available.
- The MET-SV requires a participant to meet the assessor underneath a clock, but these instructions describe a bench that the OT knew would be present in the assessment setting.
- Rules are also adjusted to make reference to the retail park’s boundaries and an increased allowance for money to be spent.

Adam was able to read through the instructions unaided. The OT stopped him after each of the three task groups to ask if he understood, before prompting him to continue. She also drew attention to the space underneath each of the information tasks and provided him with a pen to write with. For task 3, the OT changed the instruction on-the-fly, telling Adam to meet the observers back at the car instead of a bench. Adam was given a phone to check the time with, and was asked to use it to announce the time. Whilst reading the rules, the OT pointed out the area of the retail park that Adam should remain in, confining him to the car park. She then gave him 20, drawing attention to the rule that he should only spend 10. Lastly, the OT paused on the rule that Adam should not talk to the observers, indicating to him who the three observers would be and asking him if he was “okay” to be observed. Adam responded to the effect that he understood all tasks and agreed to be observed.

Finally, Adam was given an insight exercise. He was asked to rate himself out of 10 based upon how well he thought he would do in the MET. He gave a rating of 5 out of 10, which the OT explained to him was doing “some things well and some things not so well” and asked if this is what he meant. Adam agreed. Before getting out of the car and commencing the MET, Adam was prompted to check and announce the time, and was then reminded to meet the observers at the car after 20 minutes.

MET Observation

Following are a series of observations made over the course of the MET. We have highlighted these as instances of behaviour and interactions with the environment, or as cases where rules have been broken.

Of note, direct observation of Adam during the assessment was somewhat difficult. In order to minimise any influence or intrusion upon the assessment, and to attempt to reduce prompting behaviours, the OT directed the observers to maintain a distance and watch Adam through windows or from other aisles in the shops. Therefore exact utterances could not be heard, though interactions and any visible indicators of the nature of interaction were noted by the researcher. This is a constraint on our analysis and a problem for clinical professionals conducting assessments.

The assessment began poorly, with Adam leaving the car and immediately entering Argos in front of him. This meant breaking the rule to not enter a shop except to buy an item. He was seen to be showing his task sheet to an assistant, who in turn appeared to give him advice. Adam then left the shop and informed the OT that he was going to Boots, which the OT acknowledged and gently reminded him that he should not talk to the observers.

Adam entered Boots and walked past the shower gel (an item on his list) on display at the entrance, instead queuing up at the tills. He again showed his task list to an assistant at the tills, who appeared to step through the items and gave him verbal directions with physical gestures to shops that might help him. The assistant also seemed to indicate which items were purchasable in-store. Adam then walked round the store before approaching the OT again, telling her that he did not know what was meant by the instruction to buy shower gel. The OT asked him what he thought it meant, then clarified. Adam correctly went to the section signposted “Bath and Shower”, where he spent several minutes browsing before returning with a bottle of bath essence. He asked whether the bottle was what was meant by the instruction, and was asked by the OT whether the bottle was labelled shower gel. After looking and confirming that it did not, Adam admitted that he did not know where to get it. The OT prompted him to look for signs, and he returned to the correct section. At each interaction Adam was reminded not to talk to the observers, who were in an aisle on the other side of the shop.

At this point the OT decided that the observers should leave the shop in order to remove the temptation for Adam to approach them; as such, the remainder of Adam’s time in the shop was un-seen. However, he was briefly observed attempting to pay at the prescriptions counter and being directed to the tills. When he emerged from the shop, Adam had successfully bought a bottle of shower gel and a bottle of water. The OT hypothesised that he had shown his task list at the tills again and had been directed to a nearby water display.

Adam left Boots 20 minutes after the assessment had begun, but had yet to be seen checking his phone for the time. Instead he stopped outside the shop near the observers and appeared lost, looking around at shops but not making any moves towards them.

Since Adam had already broken the rule not to speak to observers multiple times, the OT elected to initiate conversation with him to prompt the next action. Adam responded that that he wanted to get seeds from Homebase, but did not know where it was. The OT asked him what he should do if he did not know where something was, to which he responded that he should ask.

Adam turned to a woman who was walking past and greeted her, but was met with the verbal response “no”. The woman did not break stride, lowering her head and continuing to walk past. Although it was not possible to ask why this response was given, the OT hypothesised that Adam’s dishevelled look had led to the woman wanting to avoid him.

Interestingly, Adam appeared unfazed by this response and instead just paused and looked around again, before approaching another woman who was loading her car nearby. He asked where he could find seeds, apparently having forgotten his previous goal to go to Homebase, and was asked for directions; Homebase was in direct line of sight from both Boots and Adam's location (see Figure 5.2) , yet he still had notable difficulty following her gestures. Adam asked the OT to follow him, and was told to go ahead.

Adam was next observed in the garden equipment section of Homebase, looking around and appearing stuck again. He moved out of sight and shortly afterwards a female customer came from that direction and called for assistance from a male shop assistant, who then led Adam to the seeds and bulbs aisle. The OT speculated that Adam had approached the female customer, who called for help on his behalf before walking off. After selecting two packs of bulbs, Adam queued and paid at the customer service desk instead of the tills, which were staffed and had no queue.

Once outside, Adam approached the OT and announced he was finished, insisting that he had completed the tasks. By this point he had only purchased shower gel, water and two bulbs (not seeds), had not purchased a hot drink, and had not attempted any of the information gathering tasks. He had not used his pen to strike off any of the tasks or to write information down. When the OT stepped through the items on the instruction list and asked whether he had bought a hot drink, Adam acknowledged that he had not completed that task. The OT began prompting him to think about where to go (the group was standing between Homebase and McDonalds), but Adam was insistent that he did not know and wanted to finish.

MET Debriefing

Once back in the car, the OT conducted a debriefing of the MET whilst still at the retail park, in order to be able to visually refer to shops and areas as necessary. She initially asked Adam whether he thought the tasks had been easy or hard, to which he responded that they were easy. The OT then worked through the list, starting with the purchased items.

It was immediately pointed out by the OT that Adam had purchased two packets of bulbs rather than a single packet of seeds. When questioned, Adam commented that he had bought two because he did not know what the OT had wanted him to get. This is similar to his earlier attempt to ask for help choosing shower gel, although there seems to be more certainty here that bulbs were the correct choice, but that he needed help selecting the variety. Although we believe that bulbs are a type of seed – and happily claim ignorance of gardening – the OT declared this to be an incorrect purchase and that she wanted specifically seeds.

Adam initially claimed that the answers to the information tasks were on the sheet, but when asked about them individually he noted that he had not gone to the relevant shops and checked. He was also unsure whether he had gone back to the car to meet the assessors after 20 minutes.

Next the OT worked through the list of rules on the instruction sheet, praising him (e.g. "Well done") on rules that he had successfully stuck to, such as remaining in the designated area. When asked whether he had stuck to the 10 spending limit, Adam laughed and acknowledged that he had spent more; a later examination of the receipts showed he had spent almost the full 20 he had been given. There was confusion regarding the rule not to enter a shop other than to buy anything, with Adam saying that he had performed "very good". When asked why he had entered Argos, he said that he had gone in to buy shower gel and water. The OT corrected him to say he had bought these in Boots, to which Adam responded that he did not know why he had gone to Argos. It is possible that Adam had intended to buy these in Argos, but this was not questioned. He also said that he "did not know" whether he had spoken to the observers during the task, although he had done on 6 occasions.

Finally, the OT returned to the insight rating Adam had been asked for at the start of the assessment, where he had rated himself a 5 out of 10 for how he would perform. When asked how he thought he had done, he gave himself a 10 out of 10, commenting that he "was a fine boy". The OT commented that he had only purchased two items, discounting the bulbs, had failed to gather information and broken some rules, and that she thought she would score him "a bit lower than that". However, Adam insisted that he should be rated a 10. Asked how he had found the assessment, he felt that it was "hard to start with but okay".

To summarise Adam's performance on the MET, Table 5.2 shows the instruction list complete with how Adam thought he had performed and his actual performance. We have included instances where Adam said that he had found answers, but then acknowledged that he had not.

5.6 Discussion of the Multiple Errands Test Observation

The observation of Adam in the MET raised a number of questions that have relevance to us in our understanding of assessment tools. The visiting researcher discussed these questions with the occupational therapist. Having identified a lack of social interactions

Task	**Adam Answer(s) (N/A indicated not asked by OT)**	**Performance**	**Pass/Fail decided by OT**
1. Purchase:			
a) A bottle of water	Bought	Bought	Pass
b) A packet of seeds	Bought	Bought 2 packets of bulbs	Fail
c) Shower gel	Bought	Bought	Pass
d) A hot drink of your choice	Did not know where to go	Not bought	Fail
2. Information:			
a) What time does the carpet shop open on a Monday?	1) Found 2) Not found	Not looked	Fail
b) What time does McDonalds stop serving breakfast?	1) Found 2) Not checked	Not looked	Fail
c) What two shops are next to Argos?	1) Found 2) Not found	Not looked	Fail
d) What time does the shoe shop close on Sunday?	1) Found 2) Not found	Not looked	Fail
Meet at the car after 20 minutes and announce the time	Not sure	Not completed	Fail
Rules:			
You must carry out all of the tasks, but may do so in any order.	N/A	Only first 3 tasks attempted	Fail
Please remain in the area of ….. retail park indicated at the beginning.	N/A	Complied	Pass
You should spend no more than £10.	Spent more	Just under \£20	Fail
No shop should be entered other than to buy something.	Completed, “very good””	Not complied, entered Argos	Fail
You should not go back into a shop you have already been in.	N/A	Complied	Pass
You should not purchase more than 2 items from any one shop.	N/A	Complied	Pass
Try to complete the exercise within 45 minutes.	N/A	Asked to finish the exercise after 35 minutes (incomplete)	Fail
Do not speak to the people observing you, unless it is part of the exercise	Not sure	Not complied - approached observers 6 times	Fail
Please keep all receipts for all items purchased	N/A	Complied	Pass

Table 5.2: Comparison of how “Adam” thought he had performed on the Multiple Errands Test, and his performance assessed by the occupational therapist

in other assessment tools, we found ourselves with an abundance of questions related to the social interactions observed in the MET.

Of note was Adam’s repeated breaching of the rule to not speak to the observers during the assessment. Although the junior occupational therapist answered two of his questions, it was the lead OT who Adam initiated conversation with and predominantly interacted with each time. The lead OT noted that Adam had more familiarity with her than with the junior OT. He never interacted with the male researcher during the visit, other than when prompted to greet him inside the rehabilitation centre. When asked about this at the end of the visit, the OT reiterated Adam’s preference to interact with women and stated that this, along with a lack of familiarity with the researcher, was why Adam had not spoken to him. This emphasises the importance of placing service users in social situations with people who they are unfamiliar with; Adam was described as having a clear preference to interact with people he was familiar with.

A pattern that we quickly recognised in Adam’s interactions with the OT was the OT’s technique of answering a question with another question. Invariably these counter-questions were prompting, such as in the following exchange:

> **Adam has brought over a bottle of bath essence in response to the instruc-*

> *tion to buy shower gel**
> *Adam: Do you mean this?*
> *OT: Does it say shower gel on it?*
> *Adam: *pause and looks* No. I don't know where to get this.*
> *OT: Where do you think you'll find something for the shower? Are there any signs that might tell you where to go?*

These responses never gave Adam the answer he was seeking, but prompted him to think about how to generate that answer. This in itself is executive – Adam is being encouraged to consider a range of options and select the one most likely to help him, rather than allowing himself to run on autopilot and offload his decision making and reasoning. This is also an instance of generative thinking, a component of executive functioning in Sohlberg and Mateer's clinical model.

Scenarios utilising these prompts were reported to be used often in the BIRT service, with roleplaying sessions used to acclimatise service users to community interactions. The OT recalled a recent training session with Adam where she had used questions such as "What would you say to me?" to prompt a response. An apparent drawback was Adam's perceived reliance on these prompts during the course of the MET, frequently approaching the OT and receiving a prompt; in some cases these were prompts to not break the rules, in others they were cues to consider a next step. The OT said that her current work with Adam was the withdrawal of these prompts.

This highlights one of the key issues with performing observations of the MET or generally in the community, in which clinical professionals have to balance the ability to observe a service user's behaviour against the risk that they will use learned offloading strategies such as prompting. The OT frequently indicated that the observers should hang back whilst following Adam, directing the group to watch him through windows, or even to engage in stealthy observations whilst browsing shop displays in an effort reminiscent of hide-and-seek.

Despite trying to remain inconspicuous, the presence of the OT, who Adam was familiar with and had rehabilitation sessions with, afforded the possibility to approach them for assistance. The OT expressed a desire for the observers to not be seen at all during MET assessments so as to witness a service user acting completely independently, as well as to be able to covertly record behaviour for debriefing and review. Neither of the OTs carried a clipboard, camera or any note-taking equipment, and the male researcher asked for permission to make notes on his phone; any pictures were taken in a lone visit later in the day.

Although the OT held this preference to remain undetected during the assessment, she acknowledged that service users could find reassurance from the presence of a familiar clinician. As we have noted in Chapter 2, the therapeutic relationship is an important part of an integrative approach. Adam demonstrated this reassurance on several occasions when he asked the OT to follow him, appearing wary of leaving her. This is a stark reminder of the long-term nature of brain injury rehabilitation. Adam had been living in a BIRT service for 8 months at the time of assessment and had spent time in hospital before that. The practical implications of prolonged living in a controlled (or semi-controlled) environment such as a rehabilitation centre mean that social interactions are constrained. We suppose an element of institutionalisation to be at work here, where Adam's request to be accompanied may reflect his unfamiliarity with being away from staff. Although it is desired that clinicians be able to observe assessments discretely, we should be aware of the distress that being alone may cause some service users and the gradual exposure to independence that may be required.

Other than talking to the OT, and slightly surprisingly, Adam did not seem to hold back from asking for help during the MET assessment. Indeed, his first action was to enter the closest shop and seemingly, since he was observed from outside, to ask for help with completing his task list. Likewise, his first instinct when entering a shop was to approach someone for help; he approached a female cashier when going into Boots, then a female customer in Homebase who called a male assistant. Interestingly, this was not his go-to response when not in a shop; he appeared visibly lost when leaving Boots and wanting to go to Homebase and needed prompting from the OT.

The OT acknowledged that this was likely to be a learned behaviour from roleplaying exercises. During the session the OT brought up a strategy she had practiced with Adam:

> *OT: If you don't know where something is, what do you do?*
> *Adam: Ask.*

There seemed to be a prioritisation challenge, again executive in nature, in utilising this practice versus the practicality of completing a task. When entering Boots, Adam passed a display at the entrance promoting shower gel, instead continuing with his goal to ask for help. The shower gel was on his list of items to buy. At this point, an efficient strategy would have been to inhibit his current behaviour and prioritise a new one: selecting a shower gel before re-evaluating the need to ask for help. This inhibition of a current behaviour and triggering a novel one is something we have discussed before in this chapter, most notably in the BADS' Rule Shift Test. (Shallice and Burgess, 1991, p.738) describe this as a "marker error", where a cognitive marker is a trigger to engage the Supervisory Attentional System to terminate a routine behaviour and engage in a non-routine task-specific action (Norman and Shallice, 1980; see Section 2.3). In this case, Adam should have stopped passively walking and begun selecting a shower gel. Adam's learned strategy of asking for help impeded his attempt to complete the tasks here; he spent time queuing up to ask instead of picking up the shower gel. Similarly, although his training had taught him to use the strategy of asking for help, he was penalised for prioritising this over following the rules when he incorrectly entered Argos for help.

A further observation was that, although Adam was capable of asking for help, his ability to make use of it was impaired. When he left Boots he commented that his next step was to look for Homebase, which he seemed to have been told by a shop assistant. His first attempt to ask a passer-by for help was unsuccessful – we will talk about this shortly. When he then approached a second passer-by, Adam asked where he could find seeds. It is here that Adam's memory impairments might have hampered his efforts to completing the tasks.

An alternative hypothesis is that his unsuccessful request for help reset his current goal. He had learned that getting seeds meant going to Homebase, so he wanted to ask where to go. When this attempt failed, he could have labelled the whole plan as having failed and reverted to finding out where he could buy seeds. Some models of executive functioning categorise this under "set switching", whereby a plan should be re-evaluated if it is found to not be working (Pennington and Ozonoff, 1996). This is typically a deficit of set switching though, rather than what we might term an overactive or premature instance of it.

Ideally we would ask Adam what had happened here. This flags up a problem when trying to interpret the behaviour of someone who might not be able to rationalise their behaviour, or for whom it is impractical to ask; the OT ruled out a review of the MET beyond the debrief due to Adam's memory deficits. Being able to show Adam a recording of himself in this situation could facilitate some insight and discussion.

5.6.1 Challenging Social Interactions

Of course, not all of Adam's attempts to ask for help were successful. The most surprising interaction during the assessment was when he approached a woman passing by, greeting her with "Hello". Her response, to lower her head, say "no" and continue walking, would have been unexpected and probably described as rude by many people in similar circumstances. We might describe it as semantically inappropriate, as it is not a typical or even uncommon response to a greeting, and certainly syntactically unusual. Such a response might, understandably, flummox even a neurotypical person in a similar situation. Remarkably, Adam appeared unfazed by this other than to briefly pause, then to make another attempt with another woman.

When asked about this, the OT said that Adam had probably been confused but not noticed any rudeness, and that his ability to recognise emotions in strangers was not strong. Adam was demonstrating a socio-cognitive impairment where he struggled to recognise and respond to emotions conveyed by other people (Williams and Wood, 2017), in this case through a bowed head and short response. However, the OT did say that he was capable of reading emotions in people he knew well, and could exhibit a good sense of humour with her and other staff at the service. This again shows the importance of practicing socio-cognition with unfamiliar people.

We were curious about this encounter with the abrupt passer-by and sought to understand whether other service users often elicited this type of response. Although responses like this were said to happen infrequently, the OT recalled assessments when service users' behaviour had been problematic. One service user had drawn the attention of security guards when he followed young girls around a shopping centre. There had been multiple cases where service users had shoplifted. Some had been accidental, where the person in question had not realised they were holding an item or had not bought it; others had been more impulsive, wanting to take an extra item from the shop but not wanting to pay for it. This had led to some difficult situations that, although defused, the OT would like to have avoided through a practice assessment.

This encounter serves to highlight a strength of community-based assessments, in which unexpected actions from service users and responses from people can present an array of challenges which might be unpredictable from centre-based exercises.

Conversely, there are service users who clinicians might want to see in difficult situations, in order to observe how they handle them. If the OT had wanted to observe Adam dealing with a confrontational member of the public, this session would not have revealed any useful information. Being able to trigger such challenging social interactions in a safe and controlled way would be helpful.

5.6.2 Strengths and Limitations of the MET

The two clinicians were asked for their thoughts on Adam's MET assessment. Their input has helped to inform the reporting and discussion of the environmental interactions and Adam's behaviour. More broadly, they described it as a fairly typical example of the MET assessments that they would usually carry out. They noted however that it was the first MET they had run in several months, despite its value. The time investment to travel to the retail park, the time investment out of staff's working day, and the cost were cited as the reasons.

The MET offers valuable observations of how impaired individuals perform socio-cognitive and functional tasks within real community settings. It allows observations of the type of behaviours that seem to have clinical significance in centre-based assessments, and additionally affords the practice of socio-cognitive skills in interactions with unfamiliar members of the public who service users might otherwise not engage with. Furthermore, it is an opportunity to see how learned strategies (e.g. prompting) translate to real settings and to practice withdrawing support.

The time taken to travel to an appropriate venue is a problem, though. Even with a nearby retail park, staff at the BIRT service in question cited time as a reason the MET is not run more often. This involves allocating a portion of the day for the service user, and for at least one clinical professional. The financial cost is also important; travel costs money, and the MET usually involves financial transactions.

There are further limitations; (Wood and Bigler, 2017, p.95) note that the MET has to be conducted "subject to the vagaries of weather, public reaction and occasional professional environment". The OTs described previous cases where security guards had become involved due to inappropriate behaviour or shoplifting occurrences.

5.6.3 Modifying the MET

The assessment conducted at the retail park is modified from the Multiple Errands Test – Simplified Version. This is to say that, although the overall structure remains the same, the tasks and rules have been adjusted for use at a specific location and can be readily adjusted to fit the target environment. The observed MET reduces the number of purchased items from 6 (MET-SV; Alderman et al., 2003) to 4, and the OT changed an instruction on-the-fly to meet at a car instead of a bench. Finding a particular and unfamiliar car may even be something of a challenge for a neurotypical participant, but it was determined to be appropriate for the assessment taking place.

We also learned from the OT that the MET would not be varied for participants of different skill levels, and that instead the same environment-specific tasks would be used. It is this tailoring to the environment that strikes us as interesting, and indeed there is apparent validity in applying the assessment to radically different environments too. The OT described an MET used within the rehabilitation centre when it could not be performed at the retail park, in which fewer rules and tasks would be used, such as "collect a cushion" in place of purchasing tasks.

There is therefore validity in taking the overall structure of the MET and tailoring it to suit a target environment. Such practice can be found in literature, with versions of the MET being developed for shopping areas (Alderman et al., 2003), hospitals (Knight et al., 2002; Morrison et al., 2013), and even specific geographical locations (Baycrest Center, Toronto; Dawson et al., 2009; Clark et al., 2017). The implication for us is that the structure and procedure for running the MET could be applied to a virtual reality environment.

5.6.4 Implications of MET for Research

In Section 5.4.4 we established a list of functional behaviours that we determined to have clinical significance through our analysis of the Behavioural Assessment of Dysexecutive Syndrome. Here we demonstrate how the MET facilitates observation of these behaviours using observations of Adam as an example:

- Inhibiting an existing behaviour and triggering a novel behaviour – Adam walked past a shower gel stand and failed to stop his current action to pick up a bottle.
- Planning out an efficient route to meet an objective – Adam was efficient in planning to buy shower gel and water in one shop. However, he did not plan ahead enough and walked past the carpet shop without completing the relevant task.
- Planning a journey around a series of constraints – Adam successfully complied with the rule to not enter a shop more than once.
- Perform interdependent steps to complete an activity – Adam was able to ask where he might find seeds before trying to find a shop. However, a deficit was observed in his ability to follow this through.
- Estimating and managing time – Adam was unable to manage his time well, using half of his time in just one shop.
- Multi-tasking between tasks – The MET had multiple tasks to complete, but performance indicated that they were attempted sequentially and not multi-tasked well.

- Exercising insight and self-awareness – Self-rating was used to predict and review performance.

We also outlined the data on functional behaviours that would be useful to collect for clinical interpretation. Below we show what data was collected to meet each of these.

- The number of errors made in tasks. The number of rule breaks and failed tasks were calculated by the clinician.
- The time spent completing tasks/sub-tasks. The clinician noted how much time the overall task had taken, but difficulty in observations hinder efforts to see how long specific sub-tasks take.
- The time spent planning for tasks. Time was allocated to prepare with the clinician, and Adam did not (but could have) planned his journey when he got out of the car.
- Properties of routes taken. Adam's rough path around the retail park was observable but not physically recorded.
- Accuracy of temporal estimation. There was a rule to finish within a certain time, and Adam's awareness of time was tested through insight.
- Reliance on prompting. The MET gave opportunities to see how often Adam needed prompting.
- Levels of insight through self-reporting. Data collected at the end.

In addition to the functional behaviours and data listed above, information about Adam's socio-cognitive skills and strategies were observed:

- Adam has been equipped with a strategy to ask for help, which he defers to quickly when faced with a new task. He is capable of employing this well, even if slowly and in conflict with completing the task more efficiently.
- His deficits to inhibiting a behaviour seems greatest when that behaviour is asking for help.
- There is a particular affinity to interacting with women, who he will approach over a man even if it means breaching a social convention (i.e. asking a customer for help instead of a shop assistant).
- There is an uneasiness about acting independently and without supervision; he is familiar with a member of the rehabilitation team and relies on her for prompting

behaviours and encouragement.

- Adam's socio-cognitive skills are such that he recognises when a conversation is over and does not engage further. However, he struggles to recognise and respond to emotions when it is not a familiar member of clinical staff.

This information paints a picture of Adam's behaviour that we believe helps rehabilitation professionals to understand his capabilities and weaknesses when faced with tasks in the community.

However, there are limitations to the Multiple Errands Test:

- It is difficult to observe people without infringing upon their independence. Knowing that a clinician is nearby can open up the potential to seek reassurance, encouragement or prompts. Clinicians would prefer to observe discretely. However, it is recognised that gradual exposure to independence in community settings might be necessary to as to not cause distress.
- Recordings of behaviour are limited. Although data can be collected for functional behaviours, such as errors made and routes taken, socio-cognitive data is difficult to record without getting close to interactions.
- Insight can be difficult to facilitate without clear data points to discuss. This might be possible with functional data (e.g. "Why did you not collect this information") but is harder for socio-cognitive data when the details of the interaction might have been forgotten (e.g. "Did you think that woman was friendly?" is a difficult question to answer of an interaction 30 minutes ago).
- Interactions are uncontrollable, where people in the community might act in a variety of manners, and there is little opportunity to ask members of the public to explain their responses.

All of these sum up to present us with considerations for our research.

The Multiple Errands Test is a useful behavioural assessment that supports observations of the functional behaviours and recording of functional data that we have identified through our analysis of centre-based assessments. Furthermore, it enables the practice of these functional everyday life skills in a community setting that is just like the real world locales they might visit when living independently. This enables service users to practice (and clinicians to observe) the compensatory strategies that they have learned during their rehabilitation and to generalise their learning to real world settings, a key goal of neurobehavioural rehabilitation (Worthington et al., 2017).

It also allows service users to engage in social interactions with people other than the clinical staff who they see on a day-to-day basis and are familiar with. This exposes them to a broader range of people who may not respond in the supportive and friendly manner that we might expect of rehabilitation staff. It supports data and observations of socio-cognitive behaviours to a degree, but the covert nature of observation in these settings mean that details of social interactions are typically missed.

We have learned that it is important to put service users in social situations with unfamiliar people to see how they react and acclimatise to independent settings. Similarly it is interesting to see how service users behave in a community setting that is far removed from the rehabilitation centre environment that they are used to. It allows for unexpected challenges to arise (e.g. shoplifting, rude interactions) which might not be easily predicted or tested for in a rehabilitation centre. Clinicians would prefer to elicit this type of behaviour in a safe clinical environment though.

The real world settings of the MET, in which anything might happen, are both a strength and limitation. It “captures the non-routine, problem solving, planning, organisation and initiative required for everyday functioning” (Wilson et al., 1996, p.235). However, there are problems with the standardisation of the MET, with some clinicians preferring to have control over challenges in order to deliver appropriate challenges to service users (Wilson et al., 1996; Wood and Bigler, 2017). Clinicians can also be wary of potential confrontation, distress or other risks that are harder to manage in the community than in a rehabilitation unit.

The time, money, and planning of the MET are also a hurdle to its regular deployment and repeatability. Clinicians would like the capability to deploy it quickly without the need to travel, so that the overheads of removing a service user from a rehabilitation centre are minimised.

The ideal then is to deliver the MET in a safe and structured rehabilitation environment, where the non-routine and challenging aspects of the assessment, such as social interactions, can be controlled by a clinician. It would also be to observe and record functional and socio-cognitive behaviours and data discretely, without interfering with the running of the assessment or giving the service user frequent opportunities to talk to familiar staff.

5.7 Conclusion

In this chapter we have set out to understand the clinical frameworks used in the behavioural assessment of executive dysfunction to show how theory currently translates to practice. We have reported on the clinical benefits of behavioural assessment as described to us through visits to Brain Injury Rehabilitation Trust services. We found that it is important for service users to have the opportunity to practice everyday living skills in community settings, so that they can exercise their learned strategies and independence. Community-based activities help to expose service users to life post-discharge and can help them work through anxiety via gradual exposure to more independent settings. From a clinician's perspective, it is helpful to understand how service users behave in everyday settings to assess their capacity to live independently and safely.

Our review of clinical frameworks focused on the Behavioural Assessment of the Dysexecutive Syndrome (Wilson et al., 1996) and the Multiple Errands Test (Shallice and Burgess, 1991). Both are used to assess behaviours by asking people with executive dysfunction to use practical skills and recording data on their performance.

In our analysis of the BADS we considered the properties of centre-based behavioural assessments that are desired by clinicians in their efforts to assess and interpret behaviour. The nature of this assessment, which abstracts real world problems to be solved hypothetically such as through pen and paper tasks, is restrictive. It offers little in the way of temptations, distractions and frustrations that would otherwise challenge a person with executive dysfunction. There is limited opportunity for external stimuli to be managed or for non-routine behaviours, for which executive control is essential, to surface. These assessments may help to provide a view of someone's functional behaviour in a rehabilitation centre, but neurobehavioural rehabilitation seeks to return people to the community with both functional and socio-cognitive skills.

We therefore observed a community-based behavioural assessment, the Multiple Errands Test, that required a service user "Adam" to perform ecologically valid activities that require management of functional and socio-cognitive skills. The MET presented non-routine activities that support the development of self-regulation and awareness of task-related behaviour, the organisation of multiple and competing tasks and information, and the ability to block out distractions and maintain attention over time – properties that (Sohlberg and Mateer, 2001, p.111) highlight as essential to observe the impact of executive dysfunction.

There are limitations to the MET that hinder attempts to observe and record relevant behaviours. It is further uncontrollable by clinicians, who may find themselves having to defuse situations or not being able to observe particular behaviours if the situation does not warrant them (e.g. handling a confrontational member of the public). It also takes time to plan and deploy the MET in the community.

We suggest that virtual reality is well-suited to simulate activities in a realistic environment, where clinicians can be given control over the challenges being delivered. Virtual reality systems, as computational simulations, are also well-placed to record data about anything taking place in the simulation. It can further be deployed within a rehabilitation centre without the need to go into the community, opening it up to people who may not be able to access community settings. We shall therefore develop a virtual reality analogue of the Multiple Errands Test. There is a precedence for modifications to be made to the MET without impeding upon its validity, with tasks being adapted to fit the target environment. In this case, the target environment is a virtual reality environment.

Through our analysis of the BADS and observation of the MET we have developed a list of behaviours that have clinical significance and described how they relate to community-based activities. We also noted some types of data that appear to be useful to clinicians in their efforts to assess and interpret behaviour (see Section 5.4.4). A virtual reality system should seek to facilitate the observation of these behaviours and recording of data. Along with these behaviours and data points, we have also refined a list of design guidelines for a virtual reality system to support behavioural assessment:

- A virtual reality environment should support assessments of individuals going about real everyday activities in the community.
- It should support assessments involving regulation of multiple tasks, pieces of information and rules with competing demands and priorities, managed over time.
- It should enable the practice of both functional and socio-cognitive everyday life skills.
- There should be distractions, temptations and frustrations to 1) challenge an individual's compulsions and inhibitions and 2) challenge them in both a functional and socio-cognitive context.
- It should enable people to practice learned strategies in real world settings independently of the prompting or offloading techniques facilitated by a clinician.

- Social interactions should be afforded with people with different personalities and temperaments.
- There should be recording of data relevant to socio-cognitive and functional behaviours to support assessment and interpretation, and facilitate insight. Recordings should support the clinician's continued role to interpret this data for clinical decision making.
- Clinicians should be given control over challenges to gradually expose people to situations of a desired difficulty, such as with social interactions.
- The environment and its assessments should be deployable in the rehabilitation centre without the overheads of removing a service user from the centre, and providing a quick escape for service users experiencing distress or agitation.

In the next chapter we shall use these design guidelines to design and develop a virtual reality environment, Virtuality Street, in which an analogue of the Multiple Errands Test can be performed.

Figure 5-2: View of the retail park from starting location

Figure 5-3: The items bought for the Multiple Errands Test

Chapter 6

Developing Virtuality Street and the VS-MET

6.1 Introduction

The exploration of virtual reality environments for acquired brain injury (ABI) rehabilitation has so far seen us develop the "Virtual Bus Stop" prototype, in which a user is waiting to board a bus and must then interact with a driver to buy a ticket (see Chapter 4). Informal feedback gathered from clinical professionals after using the prototype is summarised below:

- The fidelity of the environment received mixed feedback.
- The environment itself felt empty, with only a single character and little ambient activity to distract users.
- Emotions portrayed by the character were unconvincing and difficult to both detect and read. Clearer emotions are needed if the system is to be used by people with socio-cognitive impairments.
- Real voices were more desirable than computer-generated to facilitate socio-cognition.
- The dialogue system was slow to use, especially when unpredicted responses (e.g. statement: "I'd like a ticket please", response: "No") were used.
- The clinician should be able to see the user's view inside the VR environment.

- Scenarios could be made to increase in difficulty, such as adding ambient noise or difficult characters.
- Financial transactions felt immersion-breaking, as there was no physical exchange of money.
- Being able to look/move around or stand would feel more immersive.
- Eye gaze tracking was of interest, with clinicians interested in where somebody was looking or whether they were staring.
- Data from the environment could be tracked over time (e.g. to determine if someone is stuck).

This feedback contributes to our understanding of how virtual reality environments can be designed to support activities in clinical rehabilitation.

There were also technical constraints to the Virtual Bus Stop:

- Handing over money was implied through dialogue (e.g. "Here you go") rather than any interaction that would map onto a real world financial exchange.
- Users were required to sit down in order for headset tracking to work. This meant that movement was controlled by keyboard.
- The headset cable was also short and frequently got in the way of users.
- Movement was further restricted technically by not allowing users to move until the bus had stopped, in case they stepped into the road.
- After paying for a bus ticket, users should pick a seat. We wanted there to be a cognitive decision involved: does the person choose to sit by themselves or do they sit next to the attractive individual? With the constraint to sitting down and there being lots of chairs to choose from, this was not really practical.

The Virtual Bus Stop served to validate some of our initial design ideas and helped us to communicate with clinical professionals about their vision for VR in their practice. Clinicians saw promise in the prototype and invited us to explore how behavioural assessment in community-based settings takes place in clinical practice, including the clinical benefits and contemporary practice.

Chapter 5 built upon our understanding of clinical practice by examining some frameworks used in the assessment of neurobehavioural disability arising from executive dysfunction. There is value in rehabilitation centre-based assessments such as standard psychometric tests or roleplaying exercises to assess the components of executive functions. Neurobehavioural rehabilitation is concerned with restoring socio-cognitive and functional behaviours for independent living in the community though, and requires more accurate assessments of everyday life skills. Through our analysis of the Behavioural Assessment of Dysexecutive Syndrome (BADS) test battery and the Multiple Errands Test (MET) we developed a list of desirable behaviours to observe, and an understanding of the types of data useful to clinical professionals. Through our observation of a Brain Injury Rehabilitation Trust (BIRT) service user on the MET we learned how the MET is adapted for the environment it is being administered in, and how behaviours can be observed and recorded. We further identified some of the drawbacks to the types to this type of assessment, with cost, control and the capacity to observe and record reducing its frequency and effectiveness. We concluded with a list of design guidelines for a VR environment to support behavioural assessment in clinical practice:

- The assessment should be of individuals going about real everyday activities in the community.
- The assessment should include regulation of multiple tasks, pieces of information and rules with competing demands and priorities, managed over time.
- It should enable the practice of both functional and socio-cognitive everyday life skills.
- There should be distractions, temptations and frustrations to 1) challenge an individual's compulsions and inhibitions and 2) challenge them in both a functional and socio-cognitive context.
- It should enable people to practice learned strategies in real world settings independently of the prompting or offloading techniques facilitated by a clinician.
- Social interactions should be afforded with people with different personalities and temperaments.
- There should be recording of socio-cognitive and functional behaviours to support assessment and interpretation, and facilitate insight. Recordings should support the clinician's continued role to interpret this data for clinical decision making.
- Clinicians should be given control over challenges to gradually expose people to situations of a desired difficulty, such as with social interactions.

- The assessment should be deployable in the rehabilitation centre without the overheads of removing a service user from the centre, and providing a quick escape for service users experiencing distress or agitation.

In this chapter we report on the development of a second prototype of a virtual reality environment, Virtuality Street to assist clinical professionals in the rehabilitation of ABIs. We start by outlining an important consideration for a virtual reality environment: the VR system being used. We describe the considerations around selecting an appropriate VR system for use in rehabilitation, and justify the selection of a system, the HTC Vive, to use throughout the remainder of this research.

The implementation and features of Virtuality Street are then described, including discussion on the scope of the environment. We go on to examine locomotion techniques to enable users to traverse a VR environment and explain how we chose one for interaction in Virtuality Street. We then discuss how characters are implemented and define an interactive paradigm for users to communicate with a clinician acting as a virtual character.

With a virtual reality platform for assessment developed, we then demonstrate how an assessment can be created to work within Virtuality Street and make use of its features. Having gained an appreciation for the utility of functional assessments through our work in Chapter 5, we describe a virtual analogue of the Multiple Errands Test to run in Virtuality Street.

6.2 Previous VR MET work

Previous research has come to similar conclusions with respect to the limitations of standard neuropsychological tests and centre-based assessments such as the BADS. This research has gone on to create virtual analogues to the Multiple Errands Test.

Rand et al. (2009) present work with the Virtual Multiple Errands Test (VMET). The VMET delivers the MET inside a virtual shopping centre environment, and is an adapted version of the MET-Hospital Version (MET-HV; Knight et al., 2002). The MET-HV is similar to the MET-Simplified Version (MET-SV; Alderman et al., 2003) that our observed retail park MET was based upon, but is tailored to a hospial environment. Rand et al. adapted the MET-HV back to a shopping centre, specifically the VMall virtual supermarket environment, with tasks referring to items inside the supermarket. This involved 6 purchase tasks, 4 pieces of information, and 9 rules. A task to meet the observers after a set amount of time was replaced with checking the contents of a shopping cart after x minutes.

The VMET was administered inside a rehabilitation centre and was displayed on a 2D TV screen, with input via hand movements detected by a body tracker. Clinicians had control over the items listed on the purchasing tasks, in order to scale the difficulty. They also had control over distracting background music. The VMET has been found to be sensitive to executive function and saves both time and cost, as well as providing a safe and controllable environment for users (Jessup, 2018).

A constraint of Rand et al.'s VMET is that there are no characters present in the mall, whereas in the real world there would be people to move, help and interfere and make this a dynamic environment. As such there are no social interactions for users to navigate, making this purely an assessment of functional behaviour (Jessup, 2018).

The term "Virtual Multiple Errands Test' has been used in other research, with Cipresso et al. (2014) presenting their own VMET to detect executive dysfunction symptoms in people with Parkinson's disease. This VMET is also set in a supermarket setting and is displayed through a laptop screen, with interaction provided by a joystick. They suggest that feedback on usability is gathered for VR analogues of the MET, noting in particular that fine control with a jostick (e.g. picking up items) had been challenging for some people with motor impairments. There is no social interaction taking place in this VMET.

Parsons and McMahan (2017) report on a more recent innovation in their Virtual Environment Grocery Store, a variant of the VMET developed for the HTC Vive, which is aimed at increasing interactions with the environment to improve ecological validity. They describe studies to explore how memory and attention deficits can be exposed in the MET, using a virtual grocery store as the target environment. The scenario is that a user needs to pick up prescription medication from a pharmacist whilst shopping for groceries, and needs to attend a voucher machine after a set time. Instructions are given verbally and require the user to memorise a shopping list, drop off a prescription to a character, then shop for items whilst listening for an announcement that the prescription is ready.

Parsons and McMahan use environmental distractors to challenge inhibitory control and create a level of difficulty for users attempting the MET. These initially form a low level of distraction through ambient noise, and then increase to a high level of distraction through more intrusive audio distractors such as coughing, crying, or loudspeaker announcements. In addition to audio distractors, characters are introduced to the environment as customers. These characters do not present social interaction opportunities, instead conversing with each other or on the phone. Socio-cognition is not a concern for these studies and the characters in the Virtual Environment Grocery Store are used as distractors rather than people to converse with. Similarly, interaction with the pharmacist character is purely functional and is described as clicking on the character rather than any verbal communication that could be used to make observations about a user's socio-cognitive behaviour. This is an area that could be explored through future virtual environments and has direct relevance to the socio-cognitive interests within this thesis.

The studies reported by Parsons and McMahan use neurotypical participants from a university population. This has practical uses in assessing usability factors and the environment's capacity to produce relevant results, before being used with a clinical population. However, findings gathered with such a group should be considered cautiously as they may lack generalisability to clinical populations. Furthermore, although they may reflect a healthy baseline for comparison to impaired individuals, they could also be affected by a reduction in effort by a less-invested healthy group.

6.3 Selection of VR System

The Virtual Bus Stop prototype described in Chapter 4 was developed for the Oculus Rift Development Kit 2 and had been trialled using a VR system – a HMD, associated additional hardware, and a VR platform – belonging to the author. The success of this prototype and feedback indicating further work prompted us to purchase a VR system for the project. There were multiple driving factors for this, such as wanting a project-owned VR system that could be deployed in a BIRT hospital or given to clinicians to trial.

The primary driving force for this purchase was that the DK2 was a beta release of the Oculus Rift. It was released for early adopters to begin using it for VR development and to provide feedback on its design, usability and software bugs. This has a number of implications for us:

- The headset, though of adequate quality, was rapidly becoming outdated when compared to upcoming commercial releases. Whether visually, aesthetically, or with respect to comfort, the headset was of prototype quality and did not reflect the state of the art in VR. Whilst this by itself may not be enough of a reason to upgrade, we wanted to show what was possible with a good quality VR system.
- Awareness and acceptability of VR was increasing through the advertisement of

headsets and buy-in from well-known groups such as Facebook. There was a risk that end-users might be exposed to commercial releases of VR systems, then see our beta version as a step down or failing to live up to expectations.

- Feedback on the design and usability of the Oculus Rift led to improvements in commercial releases but did not benefit the owned DK2. Issues that we encountered in our demonstrations, such as users losing the frontal tracking when turning around, or finding the headset uncomfortable, continued to exist.
- Software support for the DK2 was announced to end at the end of 2016. Although workarounds would be possible, this increased the risk of having an unstable VR system that could negatively impact our research. Commercial releases would have official support from vendors and receive updates for performance and stability improvements.
- New features were being released in commercial VR systems, such as tracking and controllers. Such features were thought to have potential implications for the interactions that might take place in VR. We expand on this later in this section.
- The DK2 would no longer be for sale from Oculus. This means that if we decided or needed to purchase a second headset, such as to replace it if broken, we might not have been able to get another DK2. VR development requires thinking about the target platform, which in this case is the VR system being used. Continuing to develop software for the DK2 would make it more difficult to support a second headset in the future.

We therefore decided to purchase a new VR system that would be used to develop the second prototype and be used for the remainder of the project. This would give us assurances that the system would be supported by manufacturers, sold by vendors, be up to date with developments in VR technology, and could run prototype software with minimal maintenance work.

The development of the second prototype began in early 2016, at which time there were a number of VR systems either on the market or approaching release:

- Google Cardboard (Released June 2014)
- Samsung Gear VR (Released November 2015)
- Oculus Rift CV1 (Released March 2016)

- HTC Vive (Released April 2016)
- PlayStation VR (Released October 2016)

This list is not intended to be comprehensive, as at this time a variety of independent headsets were being released, typically following the Google Cardboard and Samsung Gear models of being a mount for a phone which would then run applications on one of the VR platforms. However, it presents the options that were most prevalent in the VR domain at the time and those that we looked at when determining which VR system to purchase.

A major consideration was the hardware that a VR system would run on. We grouped the systems up into those that would run on standalone smartphones (Google Cardboard, Samsung Gear VR), PCs (Oculus Rift CV1, HTC Vive), or a PlayStation (PlayStation VR). Here we discuss the decisions around this.

The Google Cardboard and Samsung Gear VR were the cheapest of the VR systems, though this did not take into account the price of the smartphone to be used. An advantage was that smartphones owned by clinical teams or even service users could potentially be used, cutting down on the cost of the system and increasing the availability of VR in hospitals. However, they came with drawbacks. Firstly, they were still dependent on particular phones; the Gear VR in particular was only compatible with certain devices, and a new version of the Gear VR was announced for release in August 2016. This raised previous concerns about systems becoming outdated and losing official support. There was the potential for a VR environment to be developed for one smartphone and have difficulty running on another. It was decided that developing for a single target platform was safer.

The feedback from our first prototype was also considered here. Feedback indicated that users should be able to look and move around, which was not afforded by the mobile VR solutions due to a lack of tracking. Next, people in the role of the "therapist" had reported wanting to see a mirror of what was viewed in VR. Reliable solutions did not exist to mirror the view from these standalone mobile VR systems, meaning that it would not be possible to view these. Lastly, we were keen to look into what data could be collected from a computational simulation of a VR activity. This was echoed in the feedback received, with enquiries into whether we could track behaviour, such as to identify instances of people being stuck. With the performance overheads and storage considerations that come with data logging, we felt that mobile VR was not as well suited as VR on other hardware. There was also the idea of a clinician scaling difficulty or controlling a character, which would require a networked solution for mobile devices.

The PlayStation VR was a possible alternative but was ruled out due to lack of familiarity with the platform. It would also require a PlayStation 4, which would be a niche purchase for both a research project and a hospital. In comparison, a PC could be used for data collection, analysis and everyday PC-related activities. Its release date was also later in the year than we wanted to wait for prototype development.

With our choice narrowed to the Oculus Rift and Vive, we looked at the features available at launch. Both had the same display resolution and field of view, so the view seen by the user would be about the same. The Oculus benefitted from in-built headphones, where the Vive required additional headphones to be purchased; although an additional cost, this did mean that there was more control over the quality of the headphones to be bought. Software development kits for a range of game development engines were available for both systems.

The availability of motion controllers was a key deciding point when choosing between the Oculus Rift and Vive. The Vive shipped with two controllers, each tracked and represented in VR; users could move the controllers around and accurately see where they were in VR. These controllers could be used to interact with the environment, or to display information. In contrast, the Oculus Rift had no motion controller support at launch, and instead typically used an Xbox controller and Oculus Remote, an untracked remote control. Oculus' own motion controllers, the Oculus Touch, were not released until the end of 2016.

Tracking was likewise a large consideration in comparing the two systems. Although both relied on external sensors to track the HMD and controllers, the Vive launched with room-scale tracking that allowed users to walk around a room to traverse a VR environment. Oculus did not officially support room-scale tracking on the Rift until 2017, when the purchase of multiple sensors was required. At the time of purchase, however, the Vive was the only VR system capable of room-scale tracking.

In summary, the PC-based VR systems, Oculus Rift and HTC Vive, were seen to better facilitate data logging, screen mirroring and software maintainability. The Vive's motion controllers and room-scale tracking were seen to better afford interaction with a virtual world, so it was chosen as the VR system to be used for the remainder of the project.

Figure 6-1:
Overhead view of Virtuality Street

6.4 Virtuality Street

Virtuality Street is the second prototype of an environment to support and deliver rehabilitation activities. It is designed to enable functional, community-based assessments to be carried out in a safe virtual reality environment that is a recognisable analogue to real world settings. Virtuality Street was developed using version 5.4.0 of Unity 3D[1], building upon the VR development techniques learned from our first prototype, and was targeted for the HTC Vive using the SteamVR SDK[2]. This section details the setting of Virtuality Street and its implemented features.

Similar to the Virtual Bus Stop prototype, Virtuality Street is centred around a single street based in the UK. No town or location was chosen to model the street on. In order to make elements of the street recognisable, and in response to feedback on the fidelity of buildings in the Virtual Bus Stop prototype, assets were obtained from Unity's Asset Store[3] or SketchUp's 3D Warehouse[4]. All assets reported in this chapter were available during Virtuality Street's development in 2016. Of note, this includes the purchasing of textures and models of typical terraced houses in the UK. Terraced housing was chosen as it enables a modular design, with the simple blocking off or opening of roads with buildings that seamlessly blend in to each other.

The main street has a single entrance and is a dead-end, with five short side roads that branch off along its length. Figure 6-1 shows an overhead view of the Virtuality Street environment to show its layout. Figures 6-2 and 6-3 show an in-environment view of Virtuality Street from the west-end and east-end of the street respectively. As shown

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[1] https://unity.com/ [accessed 19-07-2021]
[2] https://www.steamvr.com/en/ [accessed 19-07-2021]
[3] https://assetstore.unity.com/ [accessed 19-07-2021]
[4] https://3dwarehouse.sketchup.com/ [accessed 19-07-2021]

Figure 6-2:
In-environment view of Virtuality Street from the west-end

Figure 6-3:
In-environment view of Virtuality Street from the east-end

in these figures, the rear of the buildings is not modelled as it is not seen from the user's perspective. Collision detection is used to ensure that users cannot pass through the buildings, and the user is prevented from leaving the street by roadwork barriers placed at the entrance. Scaled down towers are used to give the illusion of buildings outside the walkable area.

Along with terraced housing, Virtuality Street has several "locations of interest" placed around the environment:

- Bakery

- Post office
- Pub
- Discount retailer
- Gambling shop
- Supermarket
- Phone shop
- Off license
- Takeaway

Some of these locations are informed by our discussions with clinical professionals in previous chapters. Service users who have deficits to inhibition can often struggle with gambling, smoking, drinking or eating habits, and clinicians have highlighted that shops facilitating these habits are frequent distractions and temptations when in community settings.

There are also phone boxes, post boxes, benches, a festival advertisement poster, bins and parked cars placed around the map, along with road signs.

These locations of interest can be used in rehabilitation activities and require users to navigate around Virtuality Street to find them. For example, although many shops are placed along the main street, the post office is on a side road and so would not be visible without searching. As shown in Figures 6-2 and 6-3 even buildings on the same road are not clearly visible at a distance, and so movement and searching are further required to find locations.

The implementation and distribution of locations of interest around Virtuality Street supports the design of tasks that can be scaled for users. Tasks can be designed to involve searching for and travelling to multiple locations, creating competing demands on time and requiring planning. Importantly, the design of Virtuality Street is to facilitate the creation of tasks in rehabilitation activities, not to create the tasks themselves. Section 5.4 demonstrates how Virtuality Street can be used to design tasks and activities in the creation of the VS-MET.

Ambience

Feedback from the Virtual Bus Stop prototype indicated that there should be more ambient activity in the environment, which was described as feeling empty. Several features were implemented in Virtuality Street to make it feel busier and more like a real street in the UK:

- Background town noise was acquired as a free asset and included. This noise was mostly distant traffic.
- Vehicles could be seen passing at the end of the street.
- Birds were added to fly around in the sky and periodically tweet.
- Characters were added to street.

We discuss vehicles and characters further on in this chapter.

6.4.1 Scope

As we have stated before, this is a prototype to test design ideas, facilitate communication with clinical professionals, and conduct research studies. It is not intended to be a polished product and development resources were limited, with a single research engineer responsible for developing our virtual reality environments. This meant that trade-offs needed to be made in development. Instead of modelling and producing textures from scratch, which would require training, assets (such as terraced houses from Unity's Asset Store) and third party software (modelling and rigging characters in Mixamo[5] and Adobe Fuse[6] were used. Similarly, conducting professional recordings and mixing of audio was beyond what was feasible with the available resources, so stock audio clips were used. Beyond the audiovisual fidelity of the environment, some design features had to be constrained by time, skill and other resources to form a technical scope of the prototype.

Vehicles

Although parked cars are placed along the main road, no vehicles move along this version of Virtuality Street. It is worth noting that these are added in a future version, as described in Chapter 8. The absence of vehicles was a conscious decision made on the premise that users would be moving around Virtuality Street, including being able to step into the road. This presented the question of what would happen if a user

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[5] https://www.mixamo.com/ [accessed 19-07-2021]

[6] Adobe Fuse is no longer available as of September 2020.

stepped into the path of a car. Traditional game development makes use of physics simulations, but this would cause the vehicle to push the user's camera and induce significant sensory-motor conflict. Audiovisual feedback has been used in virtual road crossing exercises, such as signalling collisions through car horns (Mesa-Gresa et al., 2011). However, design considerations remain on the consequences of this; a car might be forced to stop moving regardless of its speed pre-collision, the session might be restarted, the user's view might fade out. Given that the assessments we describe in Chapter 4 did not feature road safety or navigating road crossings, we decided that implementing vehicles was out of scope for this stage of the research and placed roadwork barriers across the entrance to the street. Vehicles could be seen to be passing beyond these roadworks to give a source to background traffic noise and to build upon the illusion of being in a busy town.

Building Interiors

Another decision regarding the technical scope of Virtuality Street was to not have building interiors. Figure 6-4 shows some early prototype work using assets to create a shop interior. The interior contains a till, shelves and cabinets, each of which afford interactions with the environment. Each of these interactions need to be considered in design – what should happen if the user waves a controller through a cabinet? Interaction is also not just limited to motion controllers. The Vive grants the ability to physically move around a space through its room-scale tracking. It is therefore easy to imagine a scenario when a user is standing in front of a shelf and steps forward in the physical world. One design response could be to allow the user to pass through the shelf, which does not reflect how the real world works. Another would be to prevent the user's view from moving forward, introducing a discrepancy between how the user moves and what they see.

A decision was therefore made that building interiors should fall outside of the scope of the first version of Virtuality Street. To facilitate tasks that might involve buildings, we instead added information to them. For example, Figure 6-5 shows the Post Office with a phone number on the outside. This phone number could then be sought as part of an information gathering task.

Time

Timekeeping has come up repeatedly in our review of assessments for executive dysfunction. From "complete this task in x minutes" to "meet me after x minutes and tell me the time", time-related instructions are common. Executive dysfunction's impact

Figure 6-4:
Early prototype work of a shop interior (not included in Virtuality Street)

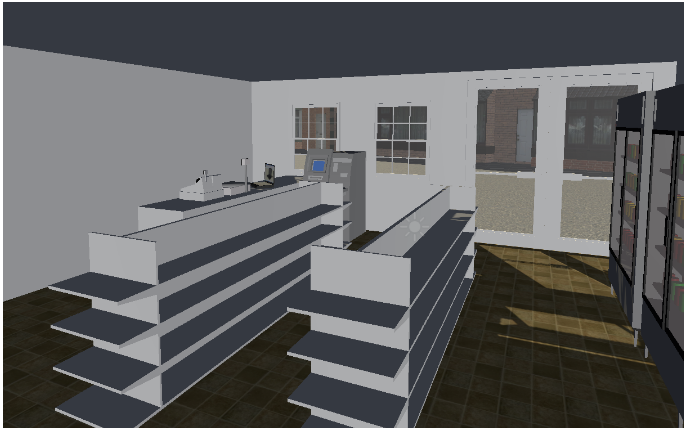

Figure 6-5:
Information is displayed on building exteriors

on temporal judgement means this is unsurprising, and demonstrates that there is value in assessing someone's ability to keep track of time. We have observed a service user being given a mobile phone to check the time on, and been told of watches being given in assessments for the same purpose. Without access to these physical objects in VR, we need another way to allow users to track time.

To this end, we implemented a clock face on one of the Vive controllers in VR. This clock shows the current real time, so that 12:34 in the real world is shown as 12:34 in VR. The clock is always present, so users can look at the Vive controller to find the time. An alternative, such as to represent a watch or mobile phone in VR, was preferable but was not implemented in this version of Virtuality Street.

6.4.2 Locomotion

A locomotion technique is the interactive paradigm that affords movement in a virtual environment, describing how a user is able to traverse from one point in the environment to another. How users move around an environment is an important consideration in VR for assessment and rehabilitation. The locomotion technique contributes to how natural an interaction with the environment is, with consequences to generalisability and validity of the rehabilitation activity (Ruddle et al., 2013). In Virtuality Street, locations of interest are dispersed across the map, with movement required to travel between buildings, shops and characters. An appropriate locomotion technique needs to enable users to move around as they perform tasks. Here we look at what the VR system can do and its limitations, examine locomotion techniques, and describe the implemented technique.

A factor in selecting the Vive was its support for room-scale tracking, which was in response to feedback on the Virtual Bus Stop scenario, where users described wanting to look around 360°, to stand up, or to move around. The Vive's room-scale tracking facilitates "real walking" around a physical space, which is mapped to walking around a virtual space. Real walking is seen as the most natural form of movement in VR, with benefits to presence, spatial awareness, and motion sickness (Langbehn and Steinicke, 2019). It is considered to have high interaction fidelity, with fine control over speed, gait and direction (Nabiyouni et al., 2015). However, it is commonly constrained by physical space limitations and the size of the tracking area. The Vive supports accurate tracking within a space that is between 2m x 1.5m and around 3.5m x 3.5m. The horizontal street shown in Figure 6-1, which spans the width of the environment, is 250m x 10m; the physical space is therefore not sufficient to fully explore the virtual reality environment. An interactive paradigm is needed for locomotion in Virtuality Street. Boletsis and Cedergren (2019) report a user experience-driven evaluation of three alternative locomotion techniques: "Walking In Place" (WIP), teleporting, and using a controller.

WIP approaches such as omnidirectional treadmills or "Hamster Balls" enable users to turn and walk in any direction whilst physically remaining in one place, but suffer from unnatural acceleration and turning (Linn, 2017). Nabiyouni et al. (2015) report that users' expectations of natural movement using this technology contributes to poor performance on locomotion-based exercises. Another WIP approach is to attach trackers to a user's body and have them walk in place, so that raising and lowering a leg is translated as a step forward in VR (Boletsis and Cedergren, 2019). Although the tracking technique is considered to be highly immersive, users can find it tiring, fear collision with real world objects and feel motion sick (Boletsis and Cedergren, 2019).

Teleportation is an increasingly used technique and has been incorporated into modern VR lobbies – virtual rooms for users to move around and select applications. Users choose a location and are teleported to it, usually with visual effects such as briefly fading the screen to black ("blinking" during teleportation) to mitigate motion sickness. Users can experience feelings of disorientation when teleporting (Rogers et al., 2019) as well as eye strain due to the blinking and shift in view (Boletsis and Cedergren, 2019). Although easy to use and fast as a locomotion technique, it suffers from low immersion, with one participant in Boletsis and Cedergren's study feeling as if they "had super-powers" (Boletsis and Cedergren, 2019, p.9). Teleportation is typically performed by selecting a destination with a controller, but there is research into gaze-controlled teleportation (Linn, 2017).

We have previously described how VR systems typically use gamepad controllers or motion controllers to interact with the environment. This extends to locomotion, with one technique being to use a controller to move around. Some implementations are game-like, where a joystick or button is pressed forward, backward or to the side (Nabiyouni et al., 2015). Another approach is to press a controller button down to move forward, with direction being determined through head or controller tracking. A variant on this is to regulate speed by using a button or trigger as a continuous input device; the further it is pressed, the faster the movement speed (Boletsis and Cedergren, 2019). Controller-driven movement has good immersion and ease of use, with controls feeling comfortable and familiar (Boletsis and Cedergren, 2019; Nabiyouni et al., 2015). However, the discrepancy between standing still and visually moving can lead to motion sickness; Boletsis and Cedergren report that users adjust to this within a few seconds of use.

A final locomotion technique receiving recent innovation is Razzaque et al. (2001)'s "redirected walking", which modifies a user's spatial perception using visual cues. For example, when a user walks forward in a straight line, slightly rotating their view in the HMD in one direction causes the user to compensate by turning to the opposite direction (Langbehn and Steinicke, 2019). In this way, a user might walk around in a circle whilst thinking they are moving forward. Camera manipulations might also be used, such as exaggerating rotations when turning or "folding" a virtual space. Haptic cues might also be used; Matsumoto et al. (2016) present an "Unlimited Corridor", in which users perceive themselves to be following a straight path whilst touching a curved wall.

This thesis is investigating how VR environments can support rehabilitation activities. We have established that functional assessments of daily living activities have value to clinical professionals, and that movement between a series of locations is a part of such assessments. It is important to have a locomotion technique to move around Virtuality Street, as tasks can be distributed across an area to create competing demands on time and to require planning. Although real walking and WIP are interesting techniques, their implementation falls outside of the scope of this research due to time and resources. Teleportation and controller movement are easy to use, however teleportation enables users to travel faster than they would naturally be able to move around the environment. This is not representative of the ecological validity we are seeking in our work, and trivialises movement that should require foresight and consideration. For instance, if someone is performing a task but is curious about a shop 100m away, they should have to weigh up the time involved in walking to it; teleporting makes this a trivial matter and encourages distracted or off-task behaviour. Due to its simplicity to both implement and use, we decided that controller movement should be used to drive locomotion around Virtuality Street.

For locomotion in Virtuality Street, a hybrid technique was implemented. Real walking around a 3m x 3m space was performed through room tracking, and users could move around this space as needed. For greater distances, controller locomotion was implemented using the trackpad on the Vive motion controller. Pressing down on the centre of the touchpad moves forward slowly, and speed can be increased by pressing further up the touchpad. Forward direction is determined by the direction of the HMD, such that a user moves in whichever direction their head is facing. This implementation is similar to the one reported by Boletsis and Cedergren (2019), except that their forward direction is determined by the controller orientation rather than the HMD.

To illustrate, Figure 6-7 shows a user standing near a poster. To read it, the user walks forward (green arrow). Once done, the user physically turns around and uses the Vive controller to move forward across the road.

Our hybrid implementation supports users as they traverse Virtuality Street, using controller-based input for exploring a large area, but retaining fine control for interacting with their immediate surroundings through physical movement.

6.5 Characters and Social Interactions

Interactions with people have been an important consideration in our work so far. Headway's interview with Alex Haller (Headway, 2013), in which he described being

Figure 6-6:
Vive controller locomotion in Virtuality Street. Pressing down on the centre of the touchpad moves forward slowly (left). Pressing further up the touchpad increases the movement speed (right).

Figure 6-7:
Illustration of movement in Virtuality Street. Real walking around a small space is shown in green, and controller locomotion across a larger area is shown in red.

rude in conversations and receiving suspicious looks from bus drivers, inspired the development of our Virtual Bus Stop prototype. In particular, it led to the development of a virtual character to play the part of a bus driver, so that a service user could practice the social interaction of buying a ticket.

An eye-opening realisation came from observing a clinician driving the character, when the clinician responded to a user's request to buy a ticket with "no". This response disrupted the storyboard we had envisioned for the conversation, in which a request would be followed by clarification if needed, then the transaction of a ticket. It also challenged the user's cognitive model of how a conversation would achieve their goal, where asking for a ticket would lead to that transaction. This highlighted that there is clinical value in introducing non-routine elements to a social interaction, to see how a user reacts and adapts their plan. Social interactions were also important in our observation of "Adam" in Chapter 5, when he similarly greeted a woman who responded "no". These interactions help clinicians to assess how someone performs in regular social settings, how they deal with difficult social cues, and how they cope with non-routine tasks. There is therefore clinical value in supporting the assessment of social interactions, and enabling clinicians to tailor responses in these interactions to challenge a service user. Here we describe how characters and social interactions are implemented in Virtuality Street to support this assessment.

The Virtual Bus Stop prototype revolved around a character, the bus driver, being driven by a clinician user interface (Figure 6-8). The clinician would select one of three available responses, with text-to-speech software synthesising an audio clip to be spoken by the character. If none of the responses were appropriate, the clinician could type in a custom response. The bus driver was animated manually frame-by-frame, with facial expressions (smiling, frowning) and body movement (sitting and turning towards the user) being simple transformations on the character's mesh (e.g. rotating the torso or raising the lips and eyes).

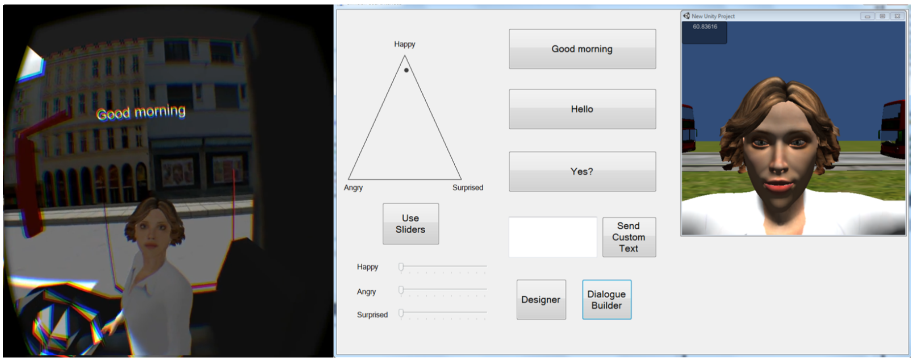

Figure 6-8:
The bus driver character and control interface from the Virtual Bus Stop prototype

Feedback on the Virtual Bus Stop prototype related to the character stated that:

- Emotions portrayed by the character were unconvincing and difficult to both detect and read. Clearer emotions are needed if the system is to be used by people with socio-cognitive impairments.
- Real voices were more desirable than computer-generated to facilitate socio-cognition.

- The dialogue system was slow to use, especially when unpredicted responses (e.g. statement: “I’d like a ticket please”, response: “No”) were used.

In response to this feedback we approached the implementation of characters in Virtuality Street differently.

Characters were created using free assets in Adobe Fuse, a 3D model creation tool with support for customisable human characters, including clothing models and textures. Fuse was also selected for its rigging support, where models are given a skeleton that can be animated. Several characters were created and rigged for use in Virtuality Street.

Rather than animating characters manually, we used a library of animations from Adobe Mixamo. The library contains a mix of full-body animations that are compatible with characters rigged in Fuse. After sampling the animations available, a set of appropriate animations, such as standing idle, texting, or talking on the phone, were downloaded and set up with our characters in Unity. Note that we include standing idle as an animation here; in response to feedback that our character seemed rigid and moved unnaturally, we animated our characters to seem more natural even when standing still. This includes breathing, shifting weight between feet, or rubbing a shoulder, rather than being completely static.

Figure 6-9 shows some of the residents of Virtuality Street. Characters are placed around the environment and can be equipped with an “animation controller” – a set of animations and conditions for their use. At present this must be done in Unity pre-build, although future development would seek to give clinicians more control over characters and their animations. In the Virtuality Street build we are reporting in this chapter, all characters have an animation controller that has them standing idle or interacting with their phones.

Along with the aforementioned animations, characters were also programmed with the capability to turn their heads towards the user, to look away periodically, and to blink. These behaviours can be toggled on or off depending on whether they are appropriate for the character; for example, a character talking on their phone should not be directing their attention towards the user.

Roaming characters who would walk around the environment were experimented with using free and paid-for pathfinding algorithms, and custom implementations. We could not find a satisfactory and, more importantly, bug-free implementation during the development of Virtuality Street. Specifically, roaming characters might get stuck,

Figure 6-9:
The residents of Virtuality Street

Figure 6-10:
Professional facial motion capture at the University of Bath[7]

walk into each other, or turn at unusual angles to avoid collisions. We also did not have an interaction paradigm for these roaming characters; for example, we questioned what should happen when a user approaches a walking character, tries to block their path, or ask them questions. This was deemed outside of scope for this implementation of Virtuality Street. One character, shown in Figure 6-9 (centre), is designed to walk away when a user is approaching her. This is a Wizard of Oz implementation, with the character simply walking forward towards an area without obstacles and despawning when out of sight of the user.

Facial Animations

Full-body animations such as standing or walking were obtained from Adobe's Mixamo library. These animations affect body parts only, describing translations to perform on a character's legs, arms, torso and head. They do not apply to a character's face, which remains a neutral default throughout these animations. We have previously discussed the effect of executive dysfunction on emotional intelligence, and implemented an emotion control in the Virtual Bus Stop prototype for clinicians to control the emotions a character is conveying (Figure 6-8). Feedback indicated that these emotions were too subtle and hard to read (Figure 6-11). To create more realistic facial animations, we decided to investigate the use of motion capture software.

Professional motion capture, involving specialist hardware and software, exists to accurately capture a user's face and visualise it as a 3d model (Figure 6-10). Although it

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[7] Image from https://www.bath.ac.uk/announcements/could-hollywood-technology-help-your-health/ [accessed 05-08-2021]

produces high fidelity animations to display emotions, it involves expensive equipment, software and expertise to use. We envision our research being used in a therapeutic setting, with clinicians deciding on the types of emotions to be portrayed, and not having access to this equipment or expertise.

To find a lower cost alternative, we investigated Adobe Mixamo's Face Plus plugin. Although discontinued along with Mixamo, Face Plus was a tool to record animations using a webcam. We created a pipeline to record a person's face, namely that of the project research engineer, and produce an animation that could be applied to any character in Virtuality Street. Figure 6-12 shows some stills of the animations created. Importantly, the images in Figure 6-12 are not static expressions conveyed by the character, but a single frame in an animation. The animations are also generalisable to any character we create, and are not limited to the one shown in Figure 6-12. Despite the software being discontinued, these facial animations demonstrate how a low cost solution could be used to record expressions and convey emotions in virtual characters.

Character Interaction

We have created a set of characters to populate Virtuality Street, obtained animations to bring them to life, and recorded facial animations to convey emotions. As we have seen from the Virtual Bus Stop prototype, literature and observations, interaction with a person is a valuable activity to assess. In the Virtual Bus Stop prototype this was achieved by a user talking out loud, then waiting for a clinician to select or type in a response which would be read out by a computer-generated voice. Feedback indicated that a real voice would be preferred by users, and that the dialogue system was slow, especially when a response needs to be typed. Some users were even confused by the unresponsiveness of the character, asking:

- "Hello?"
- "Am I doing this right?"
- "Can you hear me?"

A more responsive and adaptable dialogue system needed to allow more fluid dialogue between the clinician (as the character) and a user.

The clinical professionals who gave feedback on the Virtual Bus Stop prototype reported that they also found it difficult to split attention between choosing or typing a response and observing the user. When asked for suggestions, they referred to the roleplaying exercises carried out in clinical settings (see Section 3.5.3). The natural di-

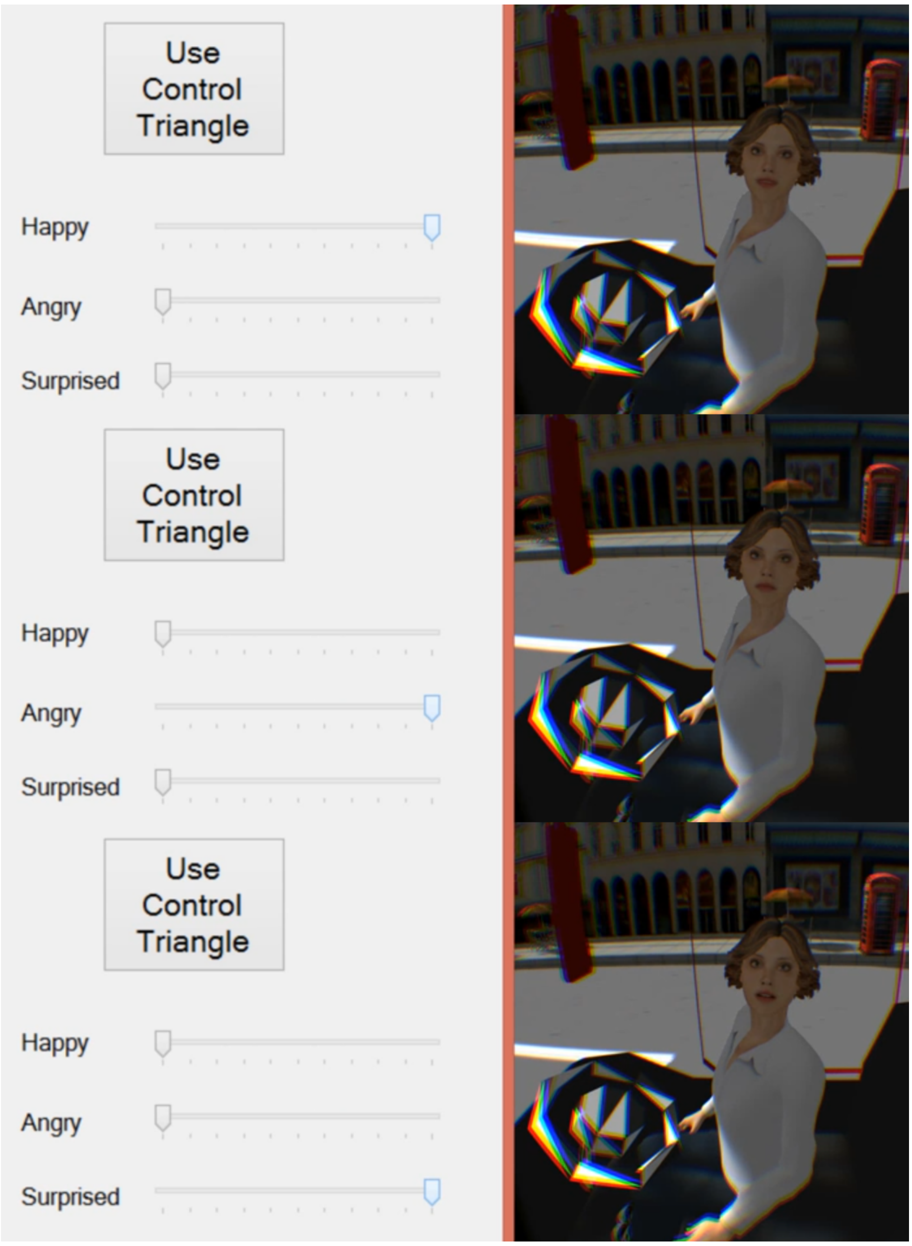


Figure 6-11:
Emotions being conveyed by a character in the Virtual Bus Stop.

Figure 6-12:
Low-cost character facial animations being driven by a webcam and Adobe Mixamo's Face Plus

alogue afforded by spoken communication in this roleplaying was described as the ideal, where a therapist could control the words and prosody being conveyed and assess how someone reacted to them. We therefore decided to use spoken communication as the paradigm through which users and clinicians/characters should interact in Virtuality Street.

As before, a user would speak out loud when wanting to communicate with a character. The controlling clinician, being located in the same room, hears the user and responds into a microphone. Their voice is projected into the virtual environment through an "Audio Source" object in Unity, which localises the sound to a particular 3D point. This means that a clinician's response can be heard in the VR environment as if it was emanating from a character. A rudimentary lip syncing algorithm was implemented to match with the volume of the clinician's utterances.

Although this is, in comparison to the Virtual Bus Stop prototype's dialogue system, a low-tech solution, the spoken communication afforded by microphone input allows for more natural interaction between a user and a character. It maintains the flexibility in choosing an appropriate response but removes the time delay in inputting it. The tone and rhythm of the character's responses can be varied depending on the challenge being delivered, enabling some scalability of the interaction difficulty as would be found in roleplaying exercises. It also allows for a real voice to be heard, which was fed back as being preferred over a computer-generated voice.

Furthermore, this implementation allows for more open-ended dialogue that could then be used to learn about the interactions that might take place between a user and a character in Virtuality Street.

6.6 Virtuality Street - Multiple Errands Test (VS-MET)

In Chapter 5 we examined how assessments could be designed to present non-routine activities that demonstrate self-regulation and awareness of task-related behaviour, the organisation of multiple and competing tasks and information, and the ability to block out distractions and maintain attention over time (Sohlberg and Mateer, 2001, p.111). These attributes are essential to be able to assess the neuropsychological and behavioural impacts of executive dysfunction. We established that a valuable assessment is one which contains a set of competing tasks interleaved with rules to moderate complexity, that is conducted in a community setting by navigating around a recognisable everyday environment. Such assessments can be used to inform clinicians' understanding of a person's behaviour in community settings, and to better predict

Figure 6-13:
Microphone input being used to drive character speech in Virtuality Street

the capability to act independently.

We observed an exemplar of community-based assessments, the Multiple Errands Test, that presents functional challenges to a service user to assess their ability to carry out everyday tasks (Shallice and Burgess, 1991). The MET was designed to challenge the organisation of behaviours and goal setting across an extended period of time and in the face of competing or conflicting tasks. Our observation showed how the MET is modified to fit the environment it is administered in, where tasks are tailored to the available information, items and locations in the target environment.

In this section we present the Virtuality Street – Multiple Errands Test (VS-MET), an adaptation of the MET where Virtuality Street is the target environment. It is based upon the observed MET at the retail park in Chapter 5, a variant of Alderman et al.'s (2003) MET-SV, but shares commonalities with other versions. The purpose of the test remains the same as previous versions: for participants to "carry out a number of tasks in situations where minor unforeseen events can occur" (Shallice and Burgess, 1991, p.733). The VS-MET comprises of the two main components found in the MET: 1) a list of tasks to complete, and 2) a set of rules to follow (Shallice and Burgess, 1991; Alderman et al., 2003; Jessup, 2018).

6.6.1 Tasks

To devise a list of tasks, we looked at the types of tasks in the retail park MET. First there were those that required obtaining information from a specified place, such as finding out the opening time of the carpet shop. We started by looking at the buildings and objects placed around Virtuality Street. As with the MET administered at the retail park, we wanted tasks to be distributed across an area in order to create a time pressure; a user could spend a lot of their time in one area, but they would need to factor in the time to walk to another area. We hypothesised that there might also be an element of frustration in needing to walk around the environment rather than find everything conveniently in one location. This first pass through the available locations gave us the following task list:

- Obtain the following information:
    - What street is the post office on?
    - What is the phone number of the post office?
    - What time does the supermarket close?
    - What time is post collected?

We then introduced additional challenges to two of the tasks, such that a user might plausibly get the wrong answer by only partially completing a task. The supermarket has two closing times: one for Monday-Friday, the other for Saturday and Sunday. We changed the relevant task to specify that the closing time for Sunday should be found. Similarly, there are multiple postboxes around Virtuality Street, with different times for different days. To create an additional challenge we added a more specific instruction, asking what time the post was collected from West Street on Saturdays.

These additional challenges came from considering the potential errors made by participants, similar to how errors in the MET are categorised by Shallice and Burgess (1991; Chapter 5). We imagined that a user might find the supermarket but forget the day, or that they might go up to the first postbox they find and look for the time without checking the street. We see this as an example of difficulty scaling, in which higher functioning participants might be given such additional challenges to further test them.

The second type of task at the retail park was a purchasing task. Feedback from the Virtual Bus Stop prototype had shown that financial exchanges felt incomplete due to being unable to hand over money. Virtuality Street also did not feature building interiors, making purchasing tasks difficult. Discounting the purchasing element of these tasks, we identified that they shared a common attribute, which was to use problem solving and creative thinking. The tasks had required Adam to buy items such as shower gel or a hot drink, but did not specify a location. Instead, he was expected to think about where he might find each item.

We designed two more tasks along these lines to require problem solving and creative thinking. The first was to find out what date a particular band was playing. The answer was found on a music festival advertisement amongst a list of band names; the expectation here was for users to look for some sort of advertisement related to music. The second task was to find out what day the bins were collected. This is a unique task in that the answer cannot be found anywhere on the street. It was inspired by the interaction between Adam and the occupational therapist at the retail park:

- OT: If you don't know where something is, what do you do?
- Adam: Ask.

Here we decided that the answer to this task could not be found by searching the environment, but would require asking a character in the street. We will expand upon this shortly.

These two information-gathering tasks were implemented instead of the MET-SV's purchasing task. In Section 5.6.3 we discussed the implications of adapting the MET to make use of the target environment. In the observed retail park MET, this involved reducing the number of tasks to be completed and changing an instruction on-the-fly. We also learned that the MET could be adapted for a significantly different environment where certain types of tasks could not be completed; for example, that the MET could be run in a rehabilitation centre with a purchasing task replaced with a "find and collect" task. The alternative tasks selected for the VS-MET do not include a purchasing component, but still require users to use similar clinically relevant skills: generative thinking and social interaction.

The final type of task is based upon the retail park instruction: "Meet me at the bench 20 minutes after you have started and tell me the time". Without an assessor represented in the virtual world, we selected a shop near the starting point and gave the instruction to go there after 5 minutes and announce the time. Of note, although the shop was specified, the name "Barrys" was not one that participants would be familiar with. We expected there to be some generative thinking being employed to understand the task instruction.

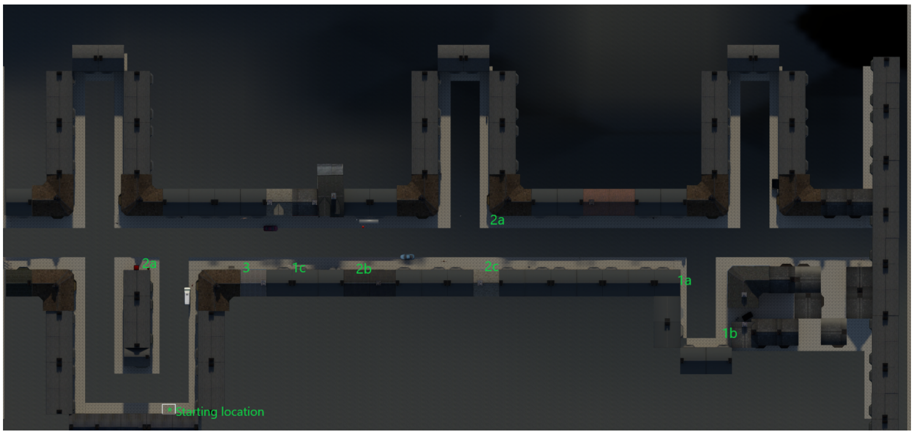


Figure 6-14:
Overhead view of Virtuality Street with task locations.

Finally, to introduce competing priorities to the VS-MET, we divided up the tasks into two groups: those that were important to complete, and those that should be tried. The full task list for the VS-MET is therefore as follows:

1. It is important to obtain the following information:
    (a) What street is the post office on?
    (b) What is the phone number of the post office?
    (c) What day are the bins collected?
2. You should try to obtain the following information:
    (a) What time is post collected from West Street on Saturdays?
    (b) What time does the supermarket close on Sundays?
    (c) What date are Sam Barber and The Outcasts playing?
3. Go to Barrys after 5 minutes and announce the time.

Figure 6-14 shows where each of the tasks can be completed.

6.6.2 Rules

To devise a list of rules, we looked at the rules provided in the retail park MET. Those involving constraints on purchasing items or entering shops were not applicable to Virtuality Street. We created a set of rules based upon those that had potential applicability in Virtuality Street:

a You may attempt the tasks in any order.

b You may only talk to people who are not using their phones.

c Try to complete the tasks and return to your starting location within 10 minutes.

The second rule, to only talk to people not using their phones, was created with two purposes. Firstly, to mimic the inhibition task of the retail park MET, where the participant is instructed not to talk to the observers. Next, it was created for practicality in constraining social interaction; we discuss this further in Section 6.6.3.

6.6.3 Social Interactions with Characters

Characters in Virtuality Street are designed to interact with users through microphone input by the clinician. In Chapter 6 we will be using the VS-MET in a lab environment with a single male researcher playing the role of the clinician. Without any voice distortion implemented, it is therefore necessary to constrain interaction in the VS-MET to a single male character, who the researcher's voice can be associated with. Having multiple characters speaking with the same voice risks being confusing to the user.

The second rule in the VS-MET, in which participants may only talk to people who are not using their phones, exists with this constraint in mind. For the VS-MET, all but two characters in Virtuality Street are set to use animations involving their phones. One is a character who walks away when approached, and the other is a male character, James, controlled by the clinician.

James uses an idle set of animations, standing in one place and periodically changing position. He looks towards the user when approached and tries to maintain eye contact, though looks off to side randomly. James can give an answer to task 2c, "What day are the bins collected?", and is the only person a user can ask for this answer. Being under clinician control, his personality can be adjusted as needed. For example, he might be played as helpful (giving the answer), as overly talkative (trying to engage the user in unrelated conversation or keep them from leaving), or confrontational (querying why the user wants to know, not being forthcoming with the answer).

The inclusion of this rule constrains permitted social interaction to a single character in the environment, enabling an interaction paradigm in which the clinician only needs to control one character.

6.7 Conclusion

In this chapter we have described the work that has gone into producing the second VR prototype, Virtuality Street, and an assessment to take place within it, the Virtuality Street MET (VS-MET). The environment and assessment have sought to incorporate the design guidelines we have developed through our research. Here we list these considerations and how this prototype/assessment has been driven by them:

- **A virtual reality environment should support assessments of individuals going about real everyday activities in the community.** The VS-MET takes place in Virtuality Street, which is modelled on a typical town located in the UK. Tasks are based upon everyday activities that might be required of someone residing in this town, such as to find a postbox. The inclusion of other buildings and objects mean that more tasks can be created if a clinician wants to vary the assessment.
- **It should support assessments involving regulation of multiple tasks, pieces of information and rules with competing demands and priorities, managed over time.** The VS-MET follows the MET structure of providing a set of tasks of varying kinds interleaved by rules to moderate complexity.
- **It should enable the practice of both functional and socio-cognitive everyday life skills.** The design of Virtuality Street is such that functional tasks can involve various street names, shops and objects. Socio-cognitive behaviours are facilitated by the inclusion of characters, which are controlled by a clinician.
- **There should be distractions, temptations and frustrations to 1) challenge an individual's compulsions and inhibitions and 2) challenge them in both a functional and socio-cognitive context.** 1) Compulsions and inhibitions are challenged through the inclusion of shops that might tempt someone prone to gambling, drinking or smoking. 2) Ambient noises such as birds, road traffic and people talking are included to be distracting or frustrating. Tasks and social interactions can also be used to challenge people in a frustrating way, such as setting far-off tasks or characters being difficult.
- **It should enable people to practice learned strategies in real world settings independently of the prompting or offloading techniques facilitated by a clinician.** The clinician is not currently represented as themselves within Virtuality Street, but is in the same room as the user to operate the character and observe.

- **Social interactions should be afforded with people with different personalities and temperaments.** Characters are implemented in Virtuality Street, and have been programmed to convey some emotions through facial expressions. Speech comes from the clinician and so can be tailored to represent different temperaments, as would be found in a roleplaying exercise.
- **There should be recording of data relevant to socio-cognitive and functional behaviours to support assessment and interpretation, and facilitate insight. Recordings should support the clinician's continued role to interpret this data for clinical decision making.** Virtuality Street performs calculations on data on all objects within it, including some data on the user. This data can be saved periodically to a file for later analysis, and screen capture and audio recordings can be used. We expand upon and demonstrate this in the next chapter.
- **Clinicians should be given control over challenges to gradually expose people to situations of a desired difficulty, such as with social interactions.** Clinicians have control over characters, who might be supportive or difficult in nature. Functional tasks can be tailored as they would in a regular MET.
- **The environment and its assessments should be deployable in the rehabilitation centre without the overheads of removing a service user from the centre, and providing a quick escape for service users experiencing distress or agitation.** Virtuality Street runs on the HTC Vive VR system, which can be deployed in any room. A hybrid interaction technique means that people can walk around a room if there is available space, but ultimately the controller is needed to move around the environment due to its size. The VR headset can be removed at any point if it is inappropriate to continue.

In Chapter 7 we will report on a lab-based study using the VS-MET to determine the potential for a virtual reality environment to observe behaviours associated with executive functions . This will further inform our understanding of how activities in a virtual reality environment support the assessment of executive dysfunction, and provide feedback to feed into future research.

Chapter 7

Identifying Clinically Relevant Behaviours in the VS-MET

7.1 Introduction

This thesis is exploring how virtual reality can support rehabilitation activities and deliver meaningful benefits to people involved with acquired brain injury rehabilitation. In our examination of the literature and current rehabilitation activities, we have established that the successful rehabilitation of executive dysfunction requires assessments of how someone behaves in real world settings. Virtual reality is capable of simulating real world scenarios safely and sufficiently to inspire realistic behaviour. We are therefore examining how VR scenarios can exercise behaviours regulated by executive functioning such that relevant observations of a person's abilities and limitations may be made.

Our work so far has focused on understanding the assessments that take place in acquired brain injury, then on developing VR environments and scenarios to mirror the properties of those assessments. This iterative process has involved taking an idea from clinical practice, considering its potential for being realised in a virtual reality environment, and getting feedback on the utility of its implementation from clinical professionals. In Chapters 3 and 4 we reviewed literature around acquired brain injuries and executive dysfunction, looking at how exercises such as roleplaying contribute to understanding someone's behaviour (Goll and Hawley, 1989, p.149), and at how the antecedents and consequences of behaviour might be assessed (McClean and Grey, 2007). This led to the development of the Virtual Bus Stop in Chapter 4 to incorporate roleplaying elements into a virtual reality scenario, and collected feedback to inform further work. We evolved our understanding of assessments of executive functioning in Chapter 5. We examined two assessments: the Behavioural Assessment of Dysexecutive Syndrome (Wilson et al., 1996) and the Multiple Errands Test (Shallice and Burgess, 1991). Our conclusion was that a valuable behavioural assessment is one which contains a set of competing tasks interleaved with rules to moderate complexity, that is conducted in a community setting by navigating around a recognisable everyday environment. Chapter 6 reported on the development of Virtuality Street as a recognisable everyday environment to administer assessments, and the Virtuality Street – Multiple Errands Test as a set of tasks and rules.

Having developed a VR scenario that we have confidence is grounded in clinical practice, we must now evaluate its capacity to challenge executive functioning and support relevant observations of a person's abilities and limitations in a community setting. In this chapter, we report a lab-based study using the VS-MET with 10 neurotypical participants. Participants were asked to complete VS-MET tasks in Virtuality Street whilst observing its rules, then given a semi-structured interview on their experiences as they watched their performance. We analyse their behaviour and performance, then conduct a thematic analysis on interview responses. The key question to be answered in this chapter is whether a range of cognitive demands can be placed upon individuals, in dimensions that correspond to established components of executive functioning.

7.2 Study Methodology

In this section we report on the methodology used to conduct this study. Virtuality Street was not evaluated by clinical professionals prior to the study. The reason for this was so that we could develop confidence in Virtuality Street as a tool to place cognitive demands on individuals, before showing it to clinical professionals (reported in Chapter 8).

7.2.1 Participants

10 neurotypical participants (6 male, 4 female) were recruited from the PhD/EngD cohort in the Department of Computer Science at the University of Bath. The exclusion criteria for the study were generated from the HTC Vive Safety and Regulatory Guide (VIVE, 2016), which provides a set of criteria to help users decide if they are safe to use the Vive. Users were asked to tell the administering researcher if, at the time of the study, they:

P	**Age**	**Gender**	**Number of hours per week playing games**	**Ever used a VR headset**	**If so, which ones**	**If so, how often**
2	20-30	F	1-2	Yes	Vive	Once a year
3	40+	M	0	No	-	-
4	30-40	F	0	Yes	Oculus Rift, Vive	Several times a year
5	20-30	F	3-4	Yes	Mobile	Once a year
6	20-30	M	1-2	Yes	Vive, Cardboard	Several times a year
7	20-30	M	7+	Yes	Oculus Rift, Vive, Gear, Cardboard	Several times a month
8	20-30	M	0	Yes	Unknown	Once a year
9	20-30	M	1-2	Yes	Oculus Rift, Cardboard	Once a year or less
10	20-30	M	7+	Yes	Oculus Rift, Vive, Gear, Hololens	Once a year or less
11	20-30	F	0	Yes	Oculus Rift	Once a year or less

Table 7.1: Table summarising demographics of participants recruited for the study. P1 is not presented as this was a member of the research team who participated as a pilot.

- Had a pre-existing heart condition.
- Were unable to safely perform physical activities.
- Had a formally diagnosed psychiatric condition such as anxiety or PTSD.
- Were pregnant.
- Were aged over 65.
- Were currently experiencing sickness, fatigue or general illness.
- Were under the influence of alcohol or drugs.

No participants reported meeting these criteria.

Participants were given a briefing sheet giving them an overview of the study, the time commitment involved, and their rights, including to be able to withdraw at any time. The exclusion criteria were listed alongside a warning for virtual reality sickness, and instructions to stop if they felt uncomfortable during the study. The briefing sheet also set out confidentiality and data retention information. Participants were then asked to consent to participating and data publication, retention and sharing. The briefing sheet and consent form are included in Appendix C.

Participants provided demographic data on their background and their experience with virtual environments. Table 7.1 summarises this data. We do not present P1 in our data, as this was a member of the research team who participated as a pilot.

The demographic variables to be collected were discussed between the researcher and supervisory/clinical teams. As described in Section 2.2.1, the core demographics of people with acquired brain injuries has historically been young men, or people aged over 65, but this has been changing. Demographics on age and gender were collected as we felt that they may provide additional context to the qualitative data being collected and its generalisability to the clinical population in question. These factors are not used in the analyses reported in this chapter but may be useful when designing future evaluations that build upon this study.

P3 was the only participant who had not used VR before. The others reported having tried a mix of headsets: Oculus Rift (n=5), Vive (n=5), Google Cardboard (n=3), Samsung Gear (n=2), and Others (n=3). Participants also indicated how often they use VR. P9, P10, and P11 responded "Never" to this question, despite reporting that they had used VR headsets before. They were questioned about this and explained that it was a more accurate description than the next option "Once a year". For instance, although having reported the highest number of VR systems tried, P10 noted that he had "only used it a few hours a year so will say never". In Table 7.1 we present these responses as "Once a year or less" to reflect the more accurate actual use rather than the reported use.

7.2.2 Gaming Experience

The demographics data includes the number of hours per week spent playing video games. This topic was discussed with the leading clinical professionals of our collaboration during the study design. Gaming experience can lead to improved navigational skills in virtual environments (Richardson et al., 2011; Smith and Du'Mont, 2009). Since tasks are distributed around Virtuality Street, we expect learning the environment and navigation to be a key skill in successful task completion. We therefore considered screening out gaming experience to reduce the effect of any advantages on task performance. Although we do not expect our neurotypical participants' behaviour and experiences to be fully representative of the brain injury population, we want to be able to make inferences about our findings' application to ABI rehabilitation. We also want to consider the resources they might use and their experiences.

The visited BIRT services had gaming consoles available for service users (see Chapter 3). Clinicians also noted that there were gamers amongst the service users residing there. In their literary survey of gaming and VR interventions for traumatic brain injury (TBI) survivors, Pietrzak et al. (2014) note that the TBI population is typically younger and likely to have had exposure to gaming. This is a stark reminder that people with brain injuries are indeed humans with their own interests and hobbies both preceding and following their injury, and there is no reason to believe that this should not apply to gaming. We are not aware of any studies that have looked at how many people with ABIs play video games, however our clinical leads expect it to mimic the general population.

One concern related to the screening of gaming experience was that the number of people aged 55+ admitted to hospital with an ABI is rising. Statistics from Headway (2021d) show that this number increased by 51% in the period between 2000-01 and 2016-17 for adults aged 55+ in England. Culturally, this age group is traditionally not associated with gaming experience. However, there are studies showing that the number of people in this age group who play games is on the rise (Statista, 2021), suggesting that gaming experience can be found across all age groups.

We chose to record gaming experience in our participants rather than screen them out. Participants self-reported the number of hours spent per week playing video games. This data is included in Table 7.1. As an observation, the 2 people who reported spending 7+ hours a week playing games were also the ones to have tried the most number of VR systems. The participants who played for 1-2 or no hours a week had typically tried fewer or no VR systems, or could not name those they had tried.

7.2.3 Data Collection Methods

The study took place in the Department of Computer Science's Interaction Lab at the University of Bath, which has an inbuilt system for recording video and audio data recording. Participants were asked to consent to being recorded for the duration of the study, and for their data to be analysed. Video and audio data was not distorted as this could interfere with analysis, and was associated exclusively with a participant number.

Participants also consented for data about their activity in the virtual environment to be collected. At 50ms intervals the Virtuality Street environment captured the following information:

- Time – how long since the Virtuality Street application has been launched.
- Camera position – the location of the VR headset in Virtuality Street.
- Camera rotation – the orientation of the VR headset.
- Object at centre – a line is drawn from the centre of the VR headset directly

forward until it meets an object (e.g. building, character, or item). The object at centre is recorded.

- Object position – the position of the object.
- Object rotation – the rotation of the object.
- Object distance – the distance of the object from the VR headset.
- Object intersection – where the line from the VR headset meets the object.
- Current velocity – the velocity of the VR headset.
- Distance to objects of interest – the distance between the VR headset and each of the objects of interest (see Section 6.4).

These data points were output to a .csv file for each participant.

As part of collecting data about activity in the virtual environment, the image being displayed in the VR headset was mirrored to a monitor and recorded as a video. This video was used as part of the study (see next section) and for analysis alongside other recorded data.

In summary, the following data was collected:

1. Participant demographics (see Section 7.2.1).
2. Video and audio recordings of the participant in a lab.
3. Data on the VR headset's position and rotation relative to components of the environment.
4. Screen capture of the image displayed in the VR headset.

Both paper-based and digital data have been stored on a secure external hard drive and duplicated onto the University of Bath's secure file system. Access to raw data remains restricted to members of the research project. All participants consented to the collection of data, its retention, and use in publications.

7.2.4 Procedure

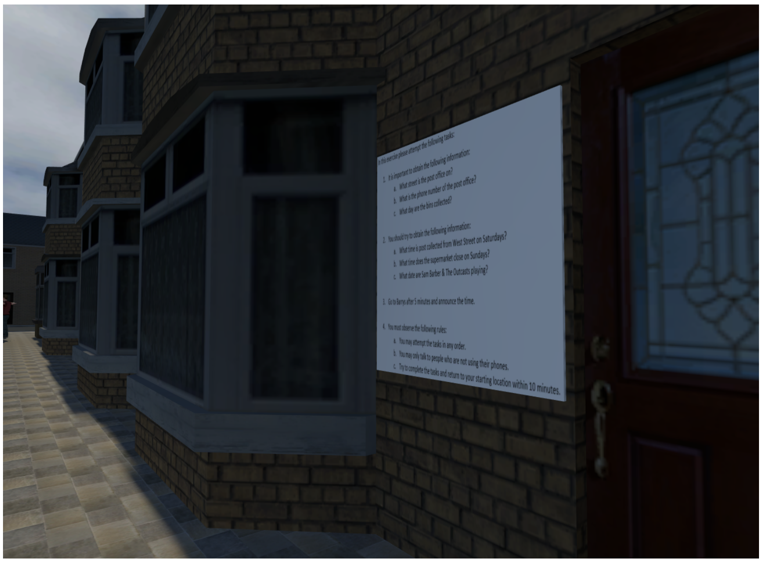
The study took place with one participant at a time, with a single researcher present. When arriving at the study, participants were given a briefing sheet and consent form. They were then asked to complete a demographics form to provide information about their background and their experience with video games and virtual reality.

Figure 7-1:
Warm-up scenario

Participants began with a warm-up scenario to acclimatise them to using the VR headset and relevant interaction techniques: moving around the virtual space and talking to a character. Regardless of their experience with virtual reality, participants were first briefed on how to put the Vive HMD and how to move around, both with the controller and physical movement around the room. The researcher then assisted the participant to put on the VR headset and ensured that it was comfortable for them. They were placed in a training room containing a character, a cross on the floor, and a stop sign (Figure 7-1). When ready, the participant was asked to move to the cross on the floor, look up at the stop sign, and then move to the character and ask for his name. The researcher provided the voice for the character, "Keith", and played him as a neutral character who simply responded to questions. All participants completed these steps successfully, and were prompted to take off the headset when they were ready.

Participants were offered a break if needed, which none took, and were asked if they felt any nausea or discomfort so far. No participants reported feeling any discomfort at this stage. All then agreed to continuing with the rest of the study.

When ready, participants were shown the VS-MET task list as a piece of physical



In this exercise please attempt the following tasks:

1. It is important to obtain the following information:
    a. What street is the post office on?
    b. What is the phone number of the post office?
    c. What day are the bins collected?
2. You should try to obtain the following information:
    a. What time is post collected from West Street on Saturdays?
    b. What time does the supermarket close on Sundays?
    c. What date are Sam Barber & The Outcasts playing?
3. Go to Barrys after 5 minutes and announce the time.
4. You must observe the following rules:
    a. You may attempt the tasks in any order.
    b. You may only talk to people who are not using their phones.
    c. Try to complete the tasks and return to your starting location within 10 minutes.

Figure 7-2:
The task list displayed on a poster inside Virtuality Street

paper. They were not talked through the task list, but instead were told that it would be represented as a poster inside the environment. They were given the following verbal instruction to go up to the poster, to read through the instructions, and then to attempt the tasks whilst thinking about the time constraints on the task list. At this point they were told of the clock on the Vive motion controller. They were then told that the task list was intended to be difficult and that they were not expected to complete all tasks, but should be mindful of the time. Lastly, they were told that they would be asked to write down the answers at the end of the exercise, before being asked to watch themselves and talk through the experience. Participants were given the opportunity to ask questions before continuing, but the researcher declined to answer any questions pertaining to the location of task answers.

Participants were again assisted to put on the VR headset and made comfortable. They started in Virtuality Street near the VS-MET task list, which was represented as a poster on the side of a building (Figure 7-2). As instructed, all participants moved up to the poster and then began to attempt the tasks.

Rule “c” of the VS-MET is to “Try to complete the tasks and return to your starting location within 10 minutes”. We allowed participants to remain in the environment for 20 minutes before prompting them to finish, however all participants opted to finish before this time.

Figure 7-3:
The character "James" controlled by the clinician.

One character in Virtuality Street, "James", was controlled by the researcher running the session. The character was played as a difficult person who would be evasive when asked questions and used an idle animation with a neutral expression (see Figure 7-3). Task persistence is a relevant executive trait in socio-cognitive behaviour, and dealing with difficult social situations is a concern of clinicians aiming to return service users to community settings. The persona was to introduce a layer of difficulty and see whether it could sufficiently challenge a participant's plan to gather information, and to observe whether they would use any real world strategies to navigate this interaction.

After finishing the VR session, participants were immediately asked to write down their answers on a physical copy of the task list. Where they commented that they could not remember an answer they had found, they were prompted by the researcher to write in what they thought the answer might be. Participants were not prompted to guess at answers they had not found in the environment. Following this, the researcher went through the task list and told the participant whether the answers were correct.

Participants were asked whether they needed a break and were happy to continue with the final part of the study – all participants agreed to continue. They were asked to watch the screen recording of their VR session in Virtuality Street, which played back a mirror of the view inside the headset. Whilst watching it they were asked to talk aloud about their planning and reasoning, and to make any remarks about their performance or the VR environment. They were also asked questions by the researcher. Questions generally fell into three categories:

- Prompts to talk about an observed behaviour or utterance – "You mentioned memorising something here, what was your strategy for that?".
- Questions about planning and reasoning – "Were you aware of the time?"; "At this point, what answers do you know?".
- Broader questions about the session or environment – "What did you think of the guy you were talking to?"

The opportunity to ask questions or seek clarification was given throughout the study, and participants were always asked if they were happy to continue with each stage. In addition, participants were encouraged to take off the VR headset or announce they wished to stop if they felt uncomfortable.

During the assessment, the researcher watched the participant to ensure that they were not going to walk into any objects, and periodically moved the headset cable to ensure that participants would not trip up.

7.3 Task Performance

In this section we present the performance of participants on the VS-MET. Participants were given a list, represented as a poster near their starting location in Virtuality Street, listing the tasks and rules of the VS-MET. The tasks required them to find locations in Virtuality Street, whilst rules constrained who they could talk to and placed time demands on them. The tasks and rules are listed below, each with an **abbreviation** to refer to and an *answer* where appropriate.

1. It is important to obtain the following information:
    - a **POStreet** What street is the post office on? *Seymour Road*
    - b **POPhone** What is the phone number of the post office? *01225 771772*
    - c **BinDay** What day are the bins collected? *Tuesday – obtained from character*
2. You should try to obtain the following information:

   a **PostTime** What time is post collected from West Street on Saturdays? *12pm*

   b **ClosingTime** What time does the supermarket close on Sundays? *10pm*

   c **MusicDate** What date are Sam Barber and The Outcasts playing? *11th November*

3. **Barrys** Go to Barrys after 5 minutes and announce the time.

4. You must observe the following rules:

   (a) **AnyOrder** You may attempt the tasks in any order.

   (b) **NoPhones** You may only talk to people who are not using their phones.

   (c) **Finishing**Try to complete the tasks and return to your starting location within 10 minutes.

Participants were asked to memorise any answers they found until the end of the VR session, when they were given a physical copy of the task list and asked to write in the answers. Table 7.3 shows the answers given by participants and their performance on tasks as appropriate. Of note, two items have been expanded to better capture participant performance. Firstly, the **Barrys** task has been split into the time taken to go to Barrys for the task (**BarrysTime**) and the announcement made (**BarrysAnnounce**). Secondly, the **Finishing** rule has been divided into returning to the starting location (**FinishLocation**) and the time spent attempting the VS-MET (**FinishTime**). The participants' time for the time-sensitive tasks began when they first stopped reading the list.

	1a POStreet	1b POPhone	1c Bin-Day	2a PostTime	2b ClosingTime	2c MusicDate	3 BarrysTime	3 BarrysAnnounce	4a AnyOrder	4b NoPhones	4c StartingLocation	4c FinishingTime
Answer	*Seymour Road*	*01225 771772*	*Tuesday*	*12pm*	*10pm*	*11th November*	*5:00*	*<Time after 5 mins>*	-	-	-	*10:00*
P2	Seymor Road	01225 771772	Tuesday	04:45	10pm	11th November	04:35	11:45	-	Pass	Fail	11:33
P3	West Street	-	-	12pm	10pm	-	07:15	13:25	-	Pass	Fail	08:25
P4	Seymour	01225 771772	Tuesday	12 noon	10pm	Sunday 11th	09:34	Half 3 (but I don't know if it's 5 minutes)	-	Pass	Pass	13:26
P5	Seamour	01255 771772	-	Noon	10pm	-	13:24	It's been 10 minutes I think	-	Pass	Task list	14:28
P6	Seymour Road	01225 771772	-	12 noon	10pm	11th November	11:55	3 minutes to 2	-	Fail (Hello to one person)	Fail	17:32
P7	Seymour Street	01225 771772	He didn't tell me (Wednesday?)	Don't know	10pm	11th November	08:40	I'm a little late but it's 12 to	-	Fail (Multiple)	Task list	12:29
P8	Seymour Street	01225 771772	-	12:00AM	10pm	-	10:10	5 to 4	-	Pass	Fail	16:50
P9	Seymour Road	01225 771772	Tuesday	12 noon	10pm	11th November	-	-	-	Pass	Fail	14:05
P10	Sainbury	01225 771772	Tuesday	12 noon	10pm	11/11	06:45	-	-	Fail (Multiple)	Fail	20:20
P11	Seymoure	01225 771772	Tuesday	12:00 noon	10pm	11th November	09:21	It is 10 past 3	-	Pass	Fail	17:20

Table 7.2: Table showing task performance

P3 asked to finish after 06:51 due to discomfort, which he described as a feeling of sickness. Since he was able to complete some tasks and continued to participate in the study afterwards, P3's data has been kept and used.

None of the participants completed all tasks and followed all rules successfully. Here we go through each of the tasks to describe participant performance.

- **1a POStreet** 3 participants provided the correct answer, and 5 provided partially correct answers (either omitting "Road" or replacing it with "Street").
- **1b POPhone** All participants except P3 found and memorised the phone number, except for P5 who misremembered one digit.
- **1c BinDay** 5 participants provided a correct answer, and 4 did not find out the required information. P7 did find out the answer but forgot, saying that the character had not told him.
- **2a PostTime** 7 participants answered correctly. P2 gave the collection time for a different day. P8 gave the answer as 12am instead of 12pm.
- **2b ClosingTime** All participants correctly found and answered the closing time of the supermarket.
- **2c MusicDate** 6 participants answered correctly. P4 gave a partial answer as "Sunday 11th", but did not note the month. The other participants failed to find this information.
- **3 BarrysTime** 9 participants attempted the Barrys task, on average 8:12 after starting. P2 performed the task 63 seconds early, P3 and P10 went at 5:41 and 6:01.
- **3 BarrysAnnounce** 7 participants announced the time correctly. P5 announced that 10 minutes had elapsed, and P10 forgot to announce anything.
- **3 Barrys (Total)** Taking the two components of this task together, we are determining that P2 and P3 pass this task.
- **4a AnyOrder** Participants completed tasks in various orders, and we do not believe there is a way to judge performance on this rule.
- **4b NoPhones** 7 participants passed this rule and did not talk to the people using phones. P6 said hello to one person texting as he walked past. P7 and P10 attempted to talk to multiple people.

	Tasks Correct	Rules Correct	Time at poster	Time attempting tasks	Interactions with controlled character	Poster visits
P2	6	1	01:34	10:55	2	3
P3	3	1	00:38	06:51	2	2
P4	5	1	00:22	12:03	1	4
P5	3	1	00:44	14:06	0	4
P6	5	0	00:44	16:56	2	3
P7	4	0	01:23	11:45	3	4
P8	3	1	00:52	15:58	1	3
P9	6	1	00:36	13:10	2	2
P10	5	0	00:58	19:36	3	2
P11	6	1	00:55	16:22	2	3

Table 7.3: Summarised results table

- **4c FinishLocation** P4 was the only participant to return to the exact starting location. P5 and P7 finished at the task list poster near the starting location. The others finished at various locations around Virtuality Street.
- **4c FinishTime** Participants spent on average 13:46 attempting the tasks and 14:38 in the environment overall (including time reading the task list). Without P3, who stopped early due to sickness, the average attempting the tasks is 14:32. No participants (other than P3) finished within 10 minutes as per the rule.
- **4c Finishing (Total)** Taking the two components of this rule together, we are determining that no participants followed this rule correctly.

Table 7.2 shows an overview of task-related behaviour and performance, presenting the number of tasks and rules completed successfully by participants, the time spent attempting tasks, the number of conversations with the researcher-controlled character, and the number of visits to the task list poster. The three participants with the highest number of poster visits (P4, P5, P7) finished at or near the poster, having returned to check the task list a final time before finishing. However we find no emerging quantitative pattern between the number of poster visits and performance on tasks and rules.

The researcher-controlled character was spoken to between 0 and 3 times. P7 and P10 conversed with the researcher-controlled character the most (x3), but also broke the “no talking to people on the phone” rule multiple times. We find that more interactions with the researcher-controlled character results in, on average, a higher overall score (Tasks Correct + Rules Correct). However, after 2 interactions, the average score drops. Although we might expect that more interaction would lead to more time in the environment, there is no discernible pattern between these; P7 and P10 exemplify this, having each spoken to the character 3 times in 10:55 and 19:36 respectively.

We also wanted to investigate whether increased visits to the task list poster would lead to a higher number of correct tasks and rules. We find no such relationship in this data, however we do see an interesting pattern between the number of visits to the task list and time spent in the environment. Except for P9 (13:10), we see that participants taking more time in the environment visited the poster less. This suggests that they were either better at memorising the task list, or were less focused on completing the tasks.

An increased amount of time in the environment might also have allowed participants to spend more time completing tasks, resulting in a higher score on tasks and rules. Again, we do not find any relationship between the time spent and the number of correct tasks and rules. For example, the highest scoring participants (P2, P9, P11) completed the tasks in a range of times (10:55, 13:10, 16:22). This suggests that some participants employed more effective strategies in using their time and managing their tasks.

This section has described participant performance on the tasks and rules of the VS-MET, as well as some quantitative data of task-related behaviours such as interacting with characters and the task list poster. Importantly, the result that none of the participants were able to successfully complete all tasks and rules indicates that the VS-MET is capable of delivering challenges to neurotypical people. We have made some observations on task performance and errors, but can only draw limited conclusions from this data. The absence of discernible patterns in the data – by which two people may score similarly despite a different number of character interactions, poster visits, or time in the environment – suggests that people are employing differing strategies to overcome challenges in the VS-MET. To expose these strategies, and the extent to which the VS-MET presents challenges to cognitive abilities known to be associated with executive functioning, we asked participants to watch themselves and answer questions about their experience.

7.4 Thematic Methodology

We have reported conducting a lab-based study in the VS-MET, where 10 neurotypical participants were asked to complete a set of tasks whilst under social and time constraints. The study is evaluating the capacity of the VS-MET to challenge executive functioning and support observations of relevant behaviours in a community setting. We have demonstrated that the VS-MET is capable of sufficiently challenging the neurotypical participants such that they are unable to complete all tasks and rules in the test. The performance metrics shows that errors exist on a range of tasks, and that different approaches were taken in how people conversed with characters, used the task list, and tracked time. Although these findings indicate the presence of challenges and strategies in the VS-MET, further analysis is required to understand the extent to which cognitive abilities associated with executive functioning are challenged, and to expose the strategies used to attempt tasks. Analysis should further aim to understand participants' experiences and perceptions of the VS-MET, as well as Virtuality Street in general, to inform our continuing development of design guidelines for virtual environments.

Thematic analysis is a qualitative analytical method, sometimes considered to be a collection of methods, that is useful to help researchers understand what has gone on in a new or unusual situation. Distinct approaches to thematic analysis are separated by their procedure and underlying philosophy. Braun and Clarke (2006) have developed a reflexive and theoretically flexible approach to thematic analysis, that acknowledges the theoretical values brought to analysis and provides a procedure for analysing data.

We conducted an adapted thematic analysis to assist in the identification of instances or recollections of experiences in Virtuality Street as they relate to the core concern of the inquiry. Our analysis was concerned with:

- The extent to which Virtuality Street and the VS-MET deliver challenges to cognitive abilities known to be associated with executive functioning.
- The strategies employed by participants to undertake tasks and comply with rules of the VS-MET.
- The capacity of the environment to expose cognitive schemas as determinants of behaviour.
- The perceptions that participants brought to and developed in Virtuality Street.

We followed the procedure for thematic analysis as described by Braun and Clarke (2006), using six distinct phases for analysis.

Phase 1: Familiarising ourselves with the data.

We transcribed the interviews with participants, using the screen capture recordings to provide additional context where needed. We read through transcripts as a complete set to become familiar with all aspects of the data, and so as to not allow any premature conclusions to exclude data and prejudice later inquiry. The transcripts were read through three times. The first pass was to familiarise ourselves with the data and identify areas that needed further context from video recordings, the second to continue with familiarisation, then a third to note down initial ideas.

Phase 2: Generating initial codes.

Our initial ideas were used to frame the interesting features of the data, by manually (pen and paper) coding the full interview data set. Braun and Clarke (2006, pp. 88-89) suggest that themes may be either data-driven or theory-driven, where the development of codes is driven by the contents of the data or by specific questions. Since we were following a reflexive approach to analysis, we acknowledged that we had some key areas of concern: the challenges presented by the VS-MET, the strategies used by participants, the cognitive schemas of how a world should work, and the experiences and perceptions of participants. We also acknowledged that design choices were made in the development of Virtuality Street that we wanted to seek feedback on: the locomotion techniques, interaction with characters, the layout of the world. These concerns, being interesting to the researcher, fed into the questions being asked to the participant to generate this data. As such the data itself is inherently driven by theory. When coding the data, we aimed to look at it broadly and code for as many potential patterns as was appropriate, even if they fell outside the scope of inquiry. The output of this phase, then, is a set of codes across the breadth of the interview data that is both data-driven and grounded in the theoretical interest of the study.

Phase 3: Searching for themes.

In this phase we took the collection of generated codes and began searching for themes within them. We created a mind map containing all codes, and then revised it to place codes in clusters with codes we considered them to be related to. For example, the codes "Character as helpful" and "Avoiding character" were both deemed to relate to the character, as they appear to contribute to a narrative about participant views of the researcher-controlled character. Some initial names were used to label each of the clusters.

Phase 4: Reviewing themes.

We reviewed and refined the set of candidate themes, assessing whether the list of codes associated with each theme accurately contributed to the theme's narrative. In some cases, codes did not fit within their theme and were moved to other themes or discarded. Some themes were also collapsed, and their codes were checked to ensure they still worked. We also developed an initial thematic map to illustrate the overall story being told by the themes.

Phase 5: Defining and naming themes.

In this phase we worked through our set of themes and defined the scope and content of each one, where the content was drawn directly from the coded data extracts that formed the themes. We then reviewed the names of each theme and looked into how each theme would portray the intended meaning.

Phase 6: Producing the report.

In the next section we will present the participant interviews conducted after attempting the VS-MET. We will use the themes derived from our analysis to frame the content of participants' responses.

7.5 Results of Thematic Analysis

Our thematic analysis of participant interviews, following the process described in the preceding section, identified the following themes.

7.5.1 Interactions with the character

All participants had interactions with the researcher-controlled character, "James", during the course of the VS-MET, and all but one (P5) conversed with him. Participants described their interactions with James in the follow-up interview, including their opinion of him. In the early exposition of candidate themes, we grouped these codes as "Character as positive" and "Character as negative". The final subthemes reflect the slightly more nuanced viewpoints of James as a character, where participants comment on Personality and Body Language with both positive and negative intonations for each. Comments relating to Personality describe how the researcher was playing the character, and what each participant picked up on from vocal utterances and prosody. Body Language is about how the character looked and physically behaved, which in Virtuality Street is concerned with the character's model and animations being played.

Personality

Most participants experienced James negatively, describing him as rude (P4, P6), annoying (P9) and grumpy (P3). Some went further, describing him as angry (P7, P11) or confrontational (P2). He was also found to be difficult to talk to and obtain answers to: "I felt like he wasn't giving straight answers to questioning" (P2). These comments reflect the researcher's aim to drive James as difficult to talk to and evasive to questions, responding with counter-questions or trying to lead people down a different topic of conversation. However, P8 perceived him differently, describing James as helpful because he had given him directions.

Body Language

Two participants made comments on James' outward appearance, describing him as looking intimidating (P11) and remarking on his eye contact: "he was looking at me: benefit" (P3). P3 was asked to clarify whether this was beneficial to interaction and said: "Absolutely, I very much value eye contact in communication. It is a sign to me that the other party is involved in the conversation, not focusing on other things, and not trying to hide something." Others echoed the eye contact when they described the character as being attentive. The lack of comments for Body Language reflects the neutral and mostly immobile stance of James throughout the assessment, where he was not intended to display any particular emotion or behaviour beyond the researcher's vocal utterances.

Consequential Behaviours

A further subtheme was the Consequential Behaviours of interactions. Some participants attempted to ask for information but terminated the conversation before getting the answer. This was either due to uncertainty over whether he would give the answer – "I asked him where the post office is and he wouldn't answer me... would he have told me after a while?" (P9) – or frustration: "I kinda felt like I can't have much more of this guy. **Even though he said he knows when the bins are collected?** Yeah yeah no, but I just couldn't take anymore of him" (P7).

Several participants described wanting to avoid James after interaction: "I avoided asking him anything else for a while" (P2). For some this manifested as preferring to seek further help elsewhere: "because I thought he was initially standoffish, it would have been nice if I had someone else I could ask then" (P7). Others wanted to physically avoid him: "I really should be walking on the other side of the street, I just couldn't be bothered. **Why the other side?** Because I found him rude and I wanted to avoid him." (P4).

In contrast to wanting to avoid James, some participants described altering their behaviour with him as a consequence to interactions. P10 became abusive in response to information not being forthcoming, insulting the character and attempting to "beat him" (P10). Some described trying to gain favour with him in order to obtain information, in some cases being “overly polite” (P2) or “trying to smooch” him (P7). Both P7 and P10 employed strategies to repair their relationship with James – “I think we got off on the wrong foot(P7)/thing(P10)” and build a rapport. P7 described his attempt to ask about James’ musical interests before enquiring after the “Sam Barber and the Outcasts” task, and P10’s plan was to convince James to provide information before hitting him.

Perception of the character as a person

All participants referred to the researcher-controlled character in their interview, describing their perception of the character as a person. Most referred to the character as a man through the use of the “he” pronoun: “I felt like he wasn’t giving straight answers to questioning” (P2); “he was quite a grumpy guy” (P3). Others noted their awareness of the researcher being in control of the character, commenting that they recognised the character’s voice or referring to the researcher instead of James: “the guy I had to talk to was quite an asshole, so uh *laugh* well I know, the guy you were supposed to be impersonating” (P9); “I recognised the voice” (P6).

Two participants went further in their description of James as a character. P5 believed he was a helper bot designed to give tips in case she got stuck, which is not completely inaccurate but fails to reflect the intention of James’ design as an everyday person in Virtuality Street. P10 described his perception of the character in detail: “Information-keeper. That’s all he was to me. I realised then that the only purpose he was there was if there was something wrong, or to get some information like the bins that were not anywhere in the real world.” P10 also discussed two occasions when he moved his face close to the character’s, noting that he would not do this in real life but that he wanted to test the boundaries of the “game”.

7.5.2 Locomotion

The locomotion technique implemented in Virtuality Street involves a hybrid of physical movement around a room and controller-driven movement, where participants would hold down the touchpad to move forward in the environment (see Section 5.3.2). Several participants commented on the locomotion technique during the session, expressing frustration verbally or through physical gestures, such as shaking the controllers. Where appropriate, participants were asked to elaborate on these instances during the interview.

Speed

Many of the comments made about locomotion during the interview were related to the controller-driven movement speed, with 8 participants feeling that the movement was too slow. 5 of these placed a condition on movement being too slow, explaining that they wanted to move faster if they had a goal: “Only when I had something I wanted to do and I knew already where I wanted to go, then I wanted to be faster” (P8); “It was the perfect pace for me like looking around but I wanted to get to the end of the road because I was like ‘there’s no post office, I need the post office’.” (P4); “I was just a bit ‘oh ok I know this street already so I don’t need to move the same speed’.” (P11). P10 suggested a “sprint function” for when users wanted to move faster. Participants also noted that the movement speed could affect their ability to remember tasks, where they might forget an answer by the time they had travelled between two locations.

Usability

Some participants reported difficulties using the locomotion technique during the exercise, specifically with regards to the controllers. Speaking about the need to press the touchpad to move for long periods, P10 commented “I hate, in all games, I hate when I have to press the same button and keep it pressed down for some time, I just hate it, I get pain in my fingers when I do that so I don’t like it”. P8 was the only participant to describe attempting to accelerate, where he would press down near the centre of the controller to move slowly and then push up to increase the speed. He noted that this was difficult though, and that he could not get used to this mechanism during the assessment.

Further comparisons to game controls were made by participants. P6 wanted to be able to move left and right, as he would expect from a game controller. Perhaps the most unusual use of locomotion came from P7, who turned around and pressed down on the touchpad to move backwards: “I start walking backwards because I thought that, I perceived that, I was actually going faster walking backwards”. It should be noted that there was no implemented difference in speed between moving backwards or forwards. P7 also “tried shaking the controller at one stage, hoping for it to go faster”, an action also attempted by P9 who “thought it could go faster, that you could run or something”. This mirrors P10’s suggestion for a “sprint function”, which is often found in games.

Physical discomfort

All participants were instructed and reminded to discontinue the exercise if they experienced any physical discomfort. We have previously noted that P3 stopped, citing nausea: “reminds me of the experience of going on rollercoasters, makes you feel sick afterwards”. He described the lack of physical feedback from movement, highlighting that “you’re not getting the accelerometer in your head telling you that you’re moving”.

Although he did not stop the session or announce any discomfort during it, P8 talked about physical discomfort during the interview, saying that he “began to feel sick because of the acceleration” but could have continued. P8 also expressed further discomfort beyond nausea: “I was getting a bit tired because the moving was. . . it wasn’t that easy”, “I was also feeling a bit dizzy from it”.

No other participants reported physical discomfort, either from the locomotion technique or otherwise. P11 was conscious of the discomfort risks when she spoke about speed, commenting that although she would have liked to have moved “twice as quick”, she “might have become dizzy”. P7 was questioned about physical discomfort when talking about his attempt to move faster by going backwards: “**Did you feel nauseous [moving backwards]?** No fine, yeah fine, totally fine.”

7.5.3 Timekeeping

During their attempt of the VS-MET, participants had access to a clock displayed on a controller, mimicking the provision of a watch or phone in the real world Multiple Errands Test. Access to a clock was intended to help participants with the time-related tasks: to go to a shop after 5 minutes and announce the time, and to try to complete the tasks and return to a starting location within 10 minutes. Participants talked about their use of the clock, and their general perception of time, during the post-assessment interview.

Use of clock

Participants generally did not make active use of the clock provided to them on the controller. Several briefly looked at the clock during the exercise but commented afterwards that they were largely unaware of doing so. “**You looked at the clock here again, any planning?** That’s really weird! I didn’t register the clock at all.” (P4). Four participants talked about actively using the clock at specific times: to plan when to go to Barry’s (P2), checking how much time was being spent reading the list (P3), making a note of the starting time (P9), and being concerned after 10 minutes had elapsed (P11). P5 “didn’t know what to do with the time”, so looked at it occasionally but did not understand its relevance until she went to Barry’s. Participants also expressed a wish to use the clock in hindsight: “Like now looking at it I kinda wish that I had looked at the times” (P4).

Despite not making use of it, both P4 and P10 expressed awareness of the clock’s presence. P4 was “a little bit excited about the fact that [she] had a clock” but noted that she only remained aware of the clock without registering the time. P10 instead gave his attention to the controller on which the clock was displayed, saying that he “was just amazed by the tech” and examining it close-up because he “was just a little bit bored just walking”.

There was also some uncertainty around how to use the clock, with P10 confused as to whether it was a stopwatch. P11 only realised near the end that “it was a normal clock, it wasn’t a specially made clock”.

Perception of time

Section 6.3 presents participants’ performance on time-related tasks. In the follow-up interview, participants commented on their perception of how long they had taken to complete the exercise or specific tasks. Some were quite accurate; P2 – who was the closest to completing in 10 minutes with 10:55 – thought she was “roughly on time”, P4 finished in 12:03 and believe she was “probably at 12 minutes”, and P10 thought “20 minutes. At least 20”, having finished in 19:36. However, some participants overestimated the amount of time that had elapsed in Virtuality Street. P7, who took 11:45 in total, said “I reckon in total I’ve been in there about 25 minutes to half an hour, potentially”. P8 thought he had gone to Barry’s after “a bit more than 20 minutes” but announced the time after 09:18.

Some participants acknowledged that they had “lost track of time” (P6, P10) during the exercise, or struggled to maintain an accurate perception of time: “Yeah that’s annoying, I had a really skewed perception of time” (P7). In some cases, participants thought that this was an accurate reflection of their timekeeping in daily life: “I usually have no concept of time anyway, so *laugh*” (P4).

7.5.4 Comparison to reality

Although not modelled on any specific location in the real world, Virtuality Street was designed to be a recognisable analogue to real world settings. In the follow up interview, participants spoke of their awareness of being in an artificial environment and their comparison of the virtual world to reality.

In the Interactions with the Character theme, some participants described their perception of the character as a person. A component to this was the impression that the character they interacted with was a bot, as would be found in a game. This comparison of Virtuality Street to a game continued in the Locomotion theme, where some participants wanted game-like controls such as the ability to move left and right, or to sprint. Some participants went further to express their perception of Virtuality Street as a game: "It's so nice to be like, to think I'm in a game, like it's the same thing that I see usually with a small character, I'm in the same building those pixels around me, it's so fun" (P5); "I felt that it's a game world" (P10).

Participants also questioned their model of how the world works, taking their model of the real world and being uncertain of how it applies to Virtuality Street. As one participant explained: "You think to yourself none of those things which I know from the real world may apply" (P3). Some tried to work out if the virtual streets worked the same way as real streets, where shops could be found clustered together: "I remembered I saw the shops down the street so I thought yeah it'll be down the high street" (P7). Similarly, some tried to use the presence of people as an indicator of where shops were: "There's no other people, because normally from the flow of people you work out which is the main street and therefore this is where all the shops are. There's not enough... there's no people, so you thought well are these just shops randomly dotted around or are they all down one street?" (P3).

Some participants commented that the environment had hindered them in their efforts to complete the tasks: "There were more shops... I didn't know exactly which store I should find the time, some of them were distracting" (P9), "There's so much other stuff, new, novel stuff that you're overloaded" (P3).

Awareness of designer

Some participants expressed awareness of the role of a designer in Virtuality Street, in some cases directly referencing how they believed the researcher had designed certain features. Speaking of the researcher-controlled character – who was never acknowledged by the researcher as being controlled – P5 said "I thought you just designed it to in case of a helper". P10 also commented on the role of the researcher: "Maybe you were trying to confuse or make tasks harder".

When explaining their approach to tasks, some participants described how they thought the tasks and answers had been designed. One belief was that answers could be found in the same order as the tasks, or that the task list dictated proximity of the answers. P5 described how she thought the answer to the first task would be the closest: “I was trying to find the post office, I thought it might be near since it was the first question”.

Many participants walked in the road during the VS-MET, rather than on the provided pavements. If they were seen doing this near the character, the researcher would provide a prompt through James. They were asked about this in the interview, at which point some commented that they had not been aware of doing so. They noted that they became more aware of this behaviour after being reminded: “I didn’t even think about walking on the pavements, I don’t know why. When he told me to walk on the pavement I found myself checking for cars and stuff a bit more which was weird.” (P2). Others said that they felt safe walking in the road in Virtuality Street, which was absent of cars: “I didn’t think this road is, I didn’t think that cars actually use this road, so. I thought [the parked van] was maybe a special postal delivery and could pass but not other characters.” Such inferences were made by participants about the road being void of moving cars and therefore safe to walk in: “I knew it was a neighbourhood street so it would be fine” (P11).

In contrast, some participants did not consider the environment when walking in the road and were aware of the researcher’s role in the design and running of the study: “I just assumed you wouldn’t run me over” (P3).

Fidelity as a cue

Participants’ use of visual cues in Virtuality Street is discussed in another theme presenting their strategies. However, some described how the graphical fidelity of objects stood out to them or helped them in their completion of tasks. Typically the quality of object textures was highlighted, with a music poster – containing the date that Sam Barber and the Outcasts were playing – being the focus of discussion. “I said ah! This must be it! **What made you think that?** Because it was a higher definition. *laugh* The resolution was better than all the other posters.” (P11). An alternative observation was that the poster stood out against nearby objects: “It was just a different colour to everything else.” (P4); “That was a poster in a wall between a shop and a wall and it was not quite fitting” (P10). However, graphical fidelity was also unhelpful at times. There was difficulty making out details of the shops: “whenever you come close to any of them it’s not clear” (P5), which led to the assumption that the shops would not have information. P4 and P5 both noted that they missed the supermarket when walking past. Text in particular was a problem, where information (e.g. the small print on the postboxes, opening hours on the supermarket) was blurry.

"I was trying to read the small characters but I wasn't able to" (P8). These issues meant that participants struggled to pick up on visual cues at times.

7.5.5 Strategies to complete list

The VS-MET required participants to complete 6 information gathering tasks, 1 meeting task, and follow 3 rules as they attempted the assessment. Participants employed some different strategies to attempt the list, with four strategies emerging: linear, prioritised, and grouping. Many decided to work from the top-down: "I just thought I'd start from the top initially" (P2), "I did try to do the first 3 in order" (P7). P5 explained that if she was given the tasks in her own language that she would read through to plan first, but went linearly with the instructions in English. P10 skimmed through the list first to look for time constraints, but then decided to approach it linearly. P6 similarly looked for priorities within the instruction wording. P9 and P4 went for a grouping approach by taking the two post office tasks, with P9 acknowledging that he knew nothing about the environment and would therefore look for a pattern: "I didn't know anything about the [tasks]... So I just thought 'oh the first two are about the post office'" (P9), "I put the post office ones together" (P4).

The participants largely spoke of searching for the post office as their first goal and getting acclimatised to the environment as they went. Some real life strategies for navigation came into play: "You have two shops here and one shop here and then the post office at the end... That's what I look for in a new city, I know the shops so I can know my direction to where I'm going." (P5), "It was easy to think where I should go for the info, because it was like the real world" (P10). The first pass through Virtuality Street helped some people to get their bearings for subsequent tasks, and participants commented on being prompted by parts of the environment: "Um, walking along, looking at all the shops, oh Barry's" (P11), "[I was] wondering whether if I go in there I'll remember what I need... and whether there's some cue in the environment" (P3).

The task to go to Barry's and announce the time after 5 minutes was also talked about. There was some confusion that Barry's was a shop, as demonstrated by P3: "**You were asking [the character] if he was Barry.** Oh yeah, I thought maybe I had to talk to Barry." (P3). This task presented problems for people who had approached the task linearly, as 5 minutes had passed by the time they returned to the task poster. Everyone who remembered the task decided to attempt it anyway: "But when I find it's 5 minutes, I had already passed 5 minutes, let's go run and do that task before it's too late." (P5, completed task after 13:24). P7 remarked how his skewed perception of time had interfered with the task: “At this point I saw I had to go to Barry’s, I knew where Barry’s was at least but... I thought I’d run out of time” (P7).

The bins task required social interaction with a character to find out what day the bins were collected, although participants could attempt to ask the character about any other task. Some participants were keen to use the strategy of asking for help: “Instead of doing anything I just wanted to go and talk to somebody” (P4). However, not all participants felt this way and preferred to manage by themselves: “So it always takes a while for me to know when I should ask someone. I always try to avoid that scenario.” (P6), “ I was looking around to find bins, maybe they had a label, before I resorted to asking, because I was frustrated I couldn’t find any other information” (P10). It would also have been helpful for some participants if they had had other characters to talk to; they wanted to employ a strategy where they would ask a second person if the first was unsuccessful: “It would have been nice if I had someone else I could ask” (P7), “Maybe [a woman on her phone] will reply, maybe tell me about the collection days” (P6). P11 managed a novel strategy in finding out the answer to the bin task, where she made use of the VR system’s tracking to jump in order to see into a rubbish skip and saw it was empty. She also saw that there were bins dotted along the road and deduced that the collection day was that day. Her strategy was then to find out what day it was in Virtuality Street – the answer was the same as the day the study was run: Tuesday, which coincidentally was the correct answer. P11 explained her thinking: “I could have just asked when the bins are collected really... but that would have been cheating! Or not... could I just ask someone? I could have just asked Barry everything”.

Along with the tasks, a set of rules needed to be followed. As a consequence of following the tasks linearly, some participants only noticed rules towards the end of their attempt: “No, yeah I totally missed that. Yeah at the bottom I missed it out completely. I went to talk to [a man with a phone], but I wasn’t aware of the no phone rule.” (P7). There was also confusion over the rule not to speak to people using their phones: “I couldn’t tell if she was on the phone or not, I didn’t know... She was texting” (P2). In contrast, two participants created their own social constraints where they thought they could not ask for an answer: “I thought there was like ‘you’re not allowed to talk to anyone, find the task and do it yourself’”.

Remembering is difficult

Participants could read a task and rule list on a poster located near their starting location. They were told that they would be writing down the answers to information tasks at the end of the session.

All participants spoke of difficulty remembering either the tasks or answers, and frustration and embarrassment was voiced at being unable to remember them clearly: “That was embarrassing cause I thought I should be able to remember it. I felt I should be able to remember a small list of things… I mean it’s only a small list *laugh*” (P3), “I was frustrated that I’d forgot the questions and had to go back to read them again”(P5). They noted that only being able to remember some tasks had required them to visit the poster multiple times, impeding their attempts to find answers.

Remembering the answers likewise hampered their attempts to complete the tasks, where participants reported forgetting answers either during or after the session: “Then when I found the actual post office I forgot the other points” (P8), “I returned to the same thing over and over again” (P11), “I think I missed some numbers [answering the post office phone number task]” (P5), “I forgot the street now *laugh* I was trying to remember the [phone] number” (P10), “At this point I realised I couldn’t remember anything, so I had to go back and check again” (P2).

There were strategies used to remember both tasks or answers. Some used the real world as a basis to remember them on: “What day are the bins collected… that’s always been important in life” (P4), “I was trying to make them a bit more real world in my head… so what I was doing was thinking if I had to find my postbox at the end of my street”. There were attempts at memorising by focusing on repetition, where some participants were heard to repeat information to themselves as they walked around or did it mentally: “I think I just kept repeating it to myself in my head” (P6). Where memory failed, participants described going back to find information again to verify it: “I was just making sure I had the right information” (P8).

Several participants described remembering tasks and answers as the most challenging part of the assessment. P3 speculated on how others might find it: “I’m thinking that if you put an elderly person in this… I think they’d just be hopelessly lost… I was thinking if you put my mother-in-law in this, who’s 85 and has got her marbles… She’d be fine just to be able to just navigate around but she wouldn’t be able to remember anything”.

Participants spoke of how they would overcome the challenge of remembering in the real world, noting that they write down information or take a picture of tasks or information: “In the real world I would always write stuff down, or take a picture because I know I will never remember” (P4), “Some sort of heads-up display that I could call… and if it had a notepad or something. So if I could have taken a picture, like in real life I would take a picture and then I'd have it on my phone" (P7). One participant, P5, commented that remembering the tasks was harder than remembering the answers, and that having the task list to carry around would have been helpful for managing her time better: "I would keep reading it while I'm walking or something" (P5).

7.5.6 Miscellaneous

Discomfort using the headset was described by two participants, independently of the physical discomfort reported earlier. Despite the researcher periodically adjusting the headset cable to ensure participants were not tangled up, P8 found that the cable had caused him problems as he was moving around. P3, who was the only participant not to have tried VR before and stopped for nausea, commented that he was "sweating like crazy" with the headset on, and described being cognitively disoriented during the session: "You feel very naïve in the environment... It was very interesting to experience yourself not being able to remember anything, that was really horrible" (P3).

7.6 Using Recordings of Behaviour

In Chapter 5 we noted the types of data that appear to be of importance to clinicians looking to observe and interpret functional behaviour:

- The number of errors made in tasks.
- The time spent completing tasks/sub-tasks.
- The time spent planning for tasks.
- Properties of routes taken.
- Accuracy of temporal estimation.
- Reliance on prompting.
- Levels of insight through self-reporting

We have reported some objective measures of task performance on the VS-MET that seeks to describe the number of errors, the time spent planning and completing tasks, and accuracy of temporal estimation.

Insight has been facilitated by asking participants to watch themselves performing tasks and talking about their behaviours. Our thematic analysis of these discussions has aimed to describe:

- The extent to which both Virtuality Street and the VS-MET deliver functional and socio-cognitive challenges to users.
- Strategies used by participants to attempt tasks and comply with rules.
- Participants' mental models of how to approach tasks.
- The perceptions brought to and developed in Virtuality Street.

Reliance on prompting was not recorded during the study, since there was no clinician to deliver prompts and the neurotypical participants we recruited had not received any training in prompting strategies. It is possible that participants could have asked a question out loud to the researcher during the study, in which case this could be described as requesting a prompt.

We are also interested in objective measures of behaviour that we have reason to believe are of interest to clinical professionals, and that may be difficult to quantify in the real world. Along with our demographics data and screen capture, computational data from Virtuality Street was logged for each participant:

- Time – how long since the Virtuality Street application has been launched.
- Camera position – the location of the VR headset in Virtuality Street.
- Camera rotation – the orientation of the VR headset.
- Object at centre – a line is drawn from the centre of the VR headset directly forward until it meets an object (e.g. building, character, or item). The object at centre is recorded.
- Object position – the position of the object.
- Object rotation – the rotation of the object.
- Object distance – the distance of the object from the VR headset.
- Object intersection – where the line from the VR headset meets the object.
- Current velocity – the velocity of the VR headset.
- Distance to objects of interest – the distance between the VR headset and each of the objects of interest (see Chapter 6, section 6.4)

To explore how this data might be used, we generated visual depictions of behaviours that we believe could be read and interpreted by clinicians to further understand a person's behaviour in the environment.

7.6.1 Routes

Properties of routes taken was identified as having clinical meaning in our analysis of the Behavioural Assessment of Dysexecutive Syndrome (BADS). Clinicians use data to look at how efficient a path around a field is, as well as how well service users can plan a route given a set of constraints. Using camera coordinate data and time, we can show the path taken by participants around Virtuality Street whilst attempting the VS-MET.

Figures 7-4, 7-5 and 7-6 show images generated for participants P2 and P11 to show their route around the environment. The colour of the line changes over time from green to red, where green lines are the participant's movement near the beginning of the session and red lines are towards the end. P2's figure shows that she spent much of her time walking in the road, and visited the post office just once during her session. P8's figure shows that he spent a lot of time near the starting location around a postbox, only finding the post office later on in the session; he also varied between the road and pavement. From P11's figure we can see that she stuck to the pavements well except when crossing, and visited more areas than the other two. P11 also travelled to the "right" end of Virtuality Street twice, once early on to find the post office, and once later on when looking for the bins.

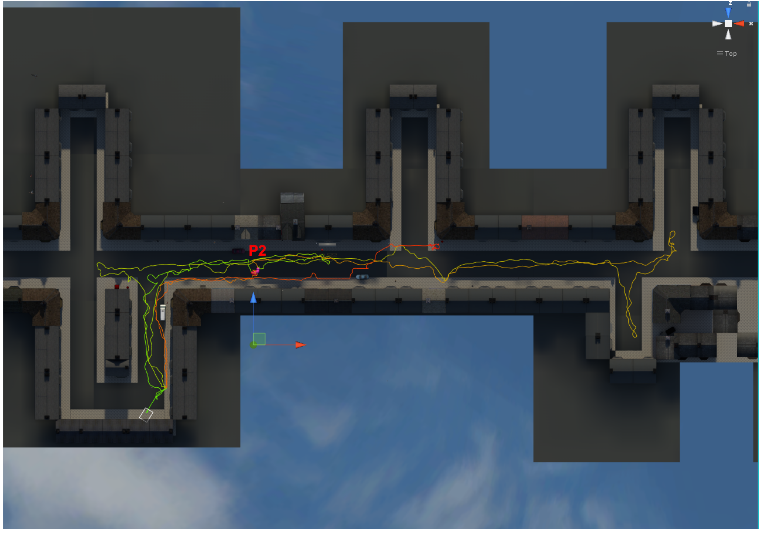
Such graphs could be used to show the number of times locations are visited, effectiveness of strategies to search the environment, and the amount of time in the road.

7.6.2 Other Measures

We suggest that data could also facilitate visual depictions of other behaviours that may have meaning to clinicians:

- A suggestion from clinicians trying the Virtual Bus Stop was that data could be used to tell when someone is stuck and unsure what to do next. We suggest that data could be used to determine when someone stops in the environment, but further research is needed to determine what a "stuck" instance looks like.
- Interpersonal distance is typically difficult to accurately measure in the real world, especially in community-based settings. Data could be used to determine how

Figure 7-4:
The path taken by P2 around the environment.



far from a character an individual is.

- Our VR headset does not use eye tracking, however it may be possible to approximate where people are looking when talking to a character. For example, if the VR headset is not pointed towards a character, we might infer that their gaze is elsewhere. Research is needed to look at how accurate such a measure might be.

7.7 Conclusion

The work in this thesis has led to the development of Virtuality Street, a community-based environment to support the rehabilitation of acquired brain injuries. We have adapted the Multiple Errands Test clinical framework for this target environment to create the VS-MET. In this chapter we have reported on a lab-based study with 10 neurotypical participants attempting the VS-MET, in order to understand the types of functional and socio-cognitive challenges they encounter within it, and to see what behaviours of clinical relevance might be observed.

Participant performance on the MET was analysed and found that no-one was able to complete the Multiple Errands test without errors. We found no discernible pattern between task performance and measures such as number of character interactions, visit to the task list poster, or time spent in the environment. The absence of such patterns suggests that people are employing different strategies to overcome challenges in the VS-MET. To expose these strategies and to facilitate self-reflection on performance,

Figure 7-5:
The path taken by P8 around the environment.

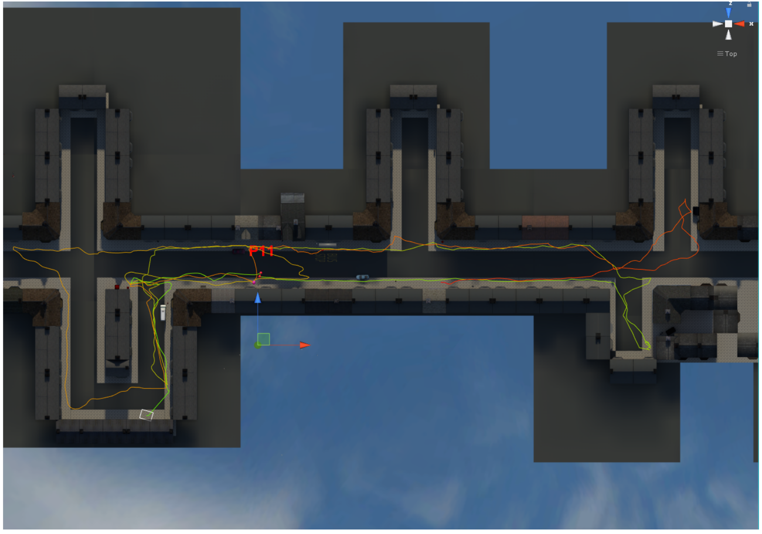
participants were asked to watch their performance back and answer questions about their experiences. We performed a thematic analysis on the results.

Participants spoke about 5 main themes, each of which has implications for our design work:

- Interactions with the character. Participants were able to recognise and respond to emotions conveyed by the researcher through a controlled character. People changed their behaviour in response to interactions with the character, where they avoided him or used strategies to build a rapport with the character. This relate to vocal dialogue though, with limited feedback on the character's body language. Further animations are needed to convey character emotions through body language, to support socio-cognitive exercises that look to recognise such signs. Some participants recognised the researcher's voice; in a clinical environment we suggest that work is needed to prevent service users recognising a familiar clinician.

- Locomotion. Mixed feedback was received on the speed of movement around the environment, with users saying it was too slow or about right. Movement speed hindered task performance at times, where answers had been forgotten during a journey. Participants spoke of wanting more control over movement when travelling a distance, or not wanting to press down on a touchpad or use game controls. Although there was little physical discomfort reported during the

Figure 7-6:
The path taken by P11 around the environment.



VS-MET, locomotion should be reviewed in future work.

- Participants were given a clock to carry around on the Vive controller, however many said that they did not use it, or did not realise the relevance of the clock until later. This suggests that more attention needs to be drawn to the clock to support timekeeping in time-sensitive exercises. Perception of time was also noted, with some feeling that VR was skewing their perception of time and others acknowledging that it reflected their timekeeping difficulties in the real world.

- Virtuality Street is intended to mirror a typical street in the UK, with shops on a high or side street. Some participants needed to look around before they realised that their model of the real world was also applicable to the virtual world. Others found that having lots of shops and being in a new environment was distracting. This points to acclimatising users to Virtuality Street before administering the VS-MET, to show that their perceptions of an everyday town are valid.

- Users spoke of being aware of the researcher as a designer, leading some of them to avoid asking for help because they thought they were being tested, or to walk in the road because they felt safe. More understanding is needed on road safety behaviours.

- Graphical fidelity both contributes to and hinders task performance, with differences in texture quality suggesting objects should be interacted with, but low quality hindering efforts to read. Work on this should seek to make textures clearer and more consistent, but is to some extent a technical constraint.

- Participants used different strategies to approach the task list. Those who went linearly without reading fully through the list ran into issues with time-constrained tasks listed further down the list, suggesting that their planning impeded their performance. There was confusion about some tasks and rules though, with participants not understanding "Barry's" was a shop or being unsure of whether texting was use of a phone.
- Remembering tasks and answers proved to be an impediment to all participants, who struggled to either remember tasks, accurately remember answers, or both. They suggest that a portable task list would help, or to have some method of writing down answers rather than having to remember them until the end.

All participants were able to rationalise their behaviour when watching their performance back, explaining what they were thinking and the strategies they were using. Some did note surprise when watching themselves though, such as seeing how long they were standing still or not remembering looking at an object. We suggest that using recordings to facilitate insight is worth exploring in future work with service users, who may have difficulties recognising and rationalising exhibited behaviour. The example of Adam from Chapter 5 is a prominent one, where he was shown poor task performance by a therapist and insisted that it was a strong performance.

Computational data is also collected by Virtuality Street, and we have demonstrated how this might be used to represent task performance visually. This is more accurate than a clinician marking it down on paper by hand, which would take minutes instead of the seconds required to do this through Virtuality Street. We propose that such visual depictions could be saved for discussion in clinical team meetings to give members of a multidisciplinary team a snapshot view of someone's performance in an assessment. Further clinical input is required to understand how this data should be used and interpreted, and how to present it such that it offers a clear depiction of behaviour.

Chapter 8

Engagement with Clinical End-Users

8.1 Introduction

The work reported in this thesis has the goal of supporting activities that offer meaningful benefits to those people who are involved with the rehabilitation of acquired brain injuries. Amongst these people, two groups are of particular interest: the users of rehabilitation services who are recovering from an injury, and the clinical professionals responsible for the day-to-day provision of these services. This has involved immersing ourselves within the clinical domain to develop an appreciation of the types of activities involved in rehabilitation, such as assessment of socio-cognitive and functional skills in the community, and to understand the challenges involved in administering these activities. Our work proposes the use of virtual reality environments as a tool to support activities of clinical relevance, and has led to the development of Virtuality Street (presented in Chapter 6). Virtuality Street is an experimental platform to articulate general design ideas, and to gather feedback on how it meets the needs and aspirations of these two groups of users through grounding in clinical practice. The ultimate goal of this clinically motivated research is an evaluation of the impact of Virtuality Street on the clinical outcomes of rehabilitation. A clinical goal of this kind falls outside of the scope of this thesis but contextualises and furthers our collaboration with the Brain Injury Rehabilitation Trust.

To this end, we are following a pathway designed in collaboration with BIRT consultants and the Research Fellow of the Disabilities Trust. This has involved participating in activities in BIRT services to expose us as HCI researchers to clinical practice, and to introduce clinicians to the principles of HCI research and virtual reality. Furthermore, this engagement has focused on input from clinical professionals. Such input is vital not only because they are the experts working in the domain, but they are the expected end users of this technology. They are also gatekeepers to service users who must have confidence in our work. It has been essential to develop trust and transparency in our process, and to ensure that clinicians retain authority and ownership of the rehabilitation process and the methods and tools that they use.

Our work in Chapter 7 provided us with valuable feedback from neurotypical volunteers, who spoke about their performance with tasks and experiences with Virtuality Street as a platform. These participants spoke of five broad themes on their interaction with characters, movement in the environment, timekeeping, comparisons to the real world, and strategies to functional tasks. This independent feedback presents useful considerations for our design work.

To build upon this, and as part of our pathway towards clinical validation, there is value in seeing how service users and clinical professionals engage with the proposed technology, and to facilitate the gathering of end-user feedback on its appeal, usability and acceptance. Such episodes of user engagement are an integral part of the overarching user-centred design strategy adopted in this thesis.

In this chapter we report on our last visit to a BIRT service to conduct engagement activities with service users and clinicians. The activities were thus planned as an integral part of the overall clinically informed iterative design philosophy that carries through the whole thesis. We also report on a visit to a specialist hospital to engage with a different set of clinical professionals, who do not belong to BIRT or DT but do work with a population undergoing rehabilitation for traumatic brain injuries. The feedback gathered from this separate hospital offers a different perspective and suggests that our research has generalisable value beyond that identified through our work with BIRT.

8.2 Adapting Virtuality Street for End-User Involvement

In preparation for gathering feedback from service users and clinical professionals, we held a demonstration and briefing session with the Disabilities Trust Research Fellow, Dr Sara da Silva Ramos, at our lab in Bath. This involved talking through the study reported in Chapter 7 and asking her to use Virtuality Street, in order to inform plans for service user involvement.

During visits to BIRT services, consultant neuropsychologists had introduced the visiting researcher to people undergoing rehabilitation. Most of these service users were mobile, however we encountered some individuals who were bed-bound or wheelchair users. For one such individual, the consultant had elected to make the introduction due to their affinity with technology and gaming. For another, it was to highlight the issues of accessing the community for critical rehabilitation activities. These were people who could benefit from activities in virtual reality, but who may be unable to engage with Virtuality Street.

Two particular issues were raised and discussed with Dr da Silva Ramos: vestibular disorders and nausea. Although had not encountered any service users with vestibular disorders, they are known form of co-morbidity with recent traumatic brain injury. We were informed that some service users residing at BIRT centres had such impairments though they are typically more severe immediately post-injury and tend to be manageable in the latter stages of rehabilitation. People with vestibular orders may experience dizziness or balancing difficulties, which could present a risk when using a standing virtual reality system. Further concerns were also raised regarding the risk of nausea, and the generalisability of learning Virtuality Street's locomotion system (see Section 6.4.2). To manage risk to service users and clinicians, we agreed that a feasible design adjustment, whilst still consistent with the core cognitive rehabilitation design concepts, would be to adapt the Virtuality Street Multiple Errands Test to a simplified sitting version.

8.2.1 VS-MET – Sitting Version

The VS-MET – Sitting Version contains several changes to the environment described in Chapter 6.

Scenario and seating

In a seated version of the VS-MET, the user begins and maintain their VR session on a chair at a fixed physical location. Their perspective on Virtuality Street is thus also from a fixed position in the virtual world. This means the proprioceptive and kinaesthetic sensations generated through their movements are in synchrony with the visual and auditory cues generated by the virtual environment, unlike modes of interaction with an unconstrained virtual world (large space) that require locomotion that the physical setting cannot support (small room). To create an immersive scenario for a user in this setting, we borrowed an idea from our early prototyping work – the premise that the user is sat at a bus stop waiting for a bus to arrive. An appropriate

Figure 8-1:
The bus stop used in the VS-MET Sitting Version.

bus stop model was added on the main road within the Virtuality Street environment, with a bench virtually positioned at the approximate height of an average physical chair. The scenario requires the user to sit at this bus stop for the duration of the assessment. So the purpose of this scenario is both to remove the need for learning locomotion techniques, and to enable people restricted to a seated position to engage with the environment in a meaningful and believable way.

The locomotion technique described in Section 6.4.2, which requires users to move by depressing buttons on a controller, remained implemented but are not required to complete the VS-MET – Sitting Version. Through headset tracking, users are still able to stand up and walk around the immediate space if desired, subject to the constraints of the room and cable length.

Task list

The tasks for users to complete needed to be simplified in order to be achievable from the seated position. Some buildings in Virtuality Street, such as the post office, were rearranged in the environment to be within sight of the seated user. This enabled them to be used in tasks. The VS-MET task list consists of a simplified set of information gathering tasks, all of which can be found from a seated position, but which nevertheless place varying social and cognitive demands on users' executive functions via requiring different degrees of interpretation and proactive engagement with elements of the scenario:

1. **What street is the post office on?** Answer: West Street. The post office can

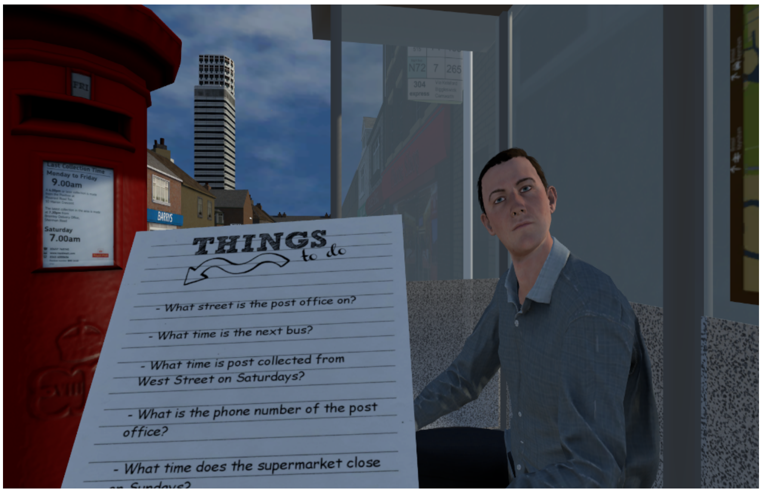


Figure 8-2:
A user reading the task list at the bus stop.

be seen nearby, and a road sign with the answer is located on the opposite side of the road.

2. **What time is the next bus?** Answer: In 10 minutes' time. Although the user is sat at a bus stop, there is no timetable nearby. Posters are placed on the bus stop where users might look for such a timetable. Instead, the controlled character is sat at the bus stop and can provide the answer if the user initiates and maintains a social interaction with them.

3. **What time is post collected from West Street on Saturdays?** Answer: 07:00. A postbox is located near to the bus stop, within reading distance.

4. **What is the phone number of the post office?** Answer: 01225 771772. The phone number is written in a large font on the outside of the post office.

5. **What time does the supermarket close on Sundays?** Answer: 10pm. The supermarket is opposite the bus stop. The opening times for Monday-Friday and Saturday-Sunday are written in a large font on the outside of the supermarket.

6. **What day are Sam Barber and the Outcasts playing?** Answer: Sunday 11th November. An advertisement poster for a music festival is displayed next to the user on the side of the bus stop.

The fact that a set of tasks is given all at once is also meaningful from an executive functioning perspective: the user must manage initiation, maintenance and disengage-

Figure 8-3:
Cars driving along the road during the VS-MET Sitting Version.

ment from each one in order to engage in all six activities. The task list is displayed on one of the Vive controllers, which is given to a user at the start of the session. The list is mapped to the controller, so a user can lower it to look around or raise it to view the tasks.

Vehicles

Cars drive past the bus stop at random intervals, some of them with loud music. This is to provide a distraction when completing the tasks, as well as to give the impression that the road is being actively used. In Chapter 7's **Comparison to reality** theme (see Section 7.5.4), some participants had commented that the absence of traffic left them feeling overly safe walking in the road, or that they were not using a real street.

Since users are expected to remain sitting during the task, they are not anticipated to step into the road. However, since users can feasibly stand up and move around (subject to space), the vehicles are programmed to stop moving immediately if an object is detected in front of them, to prevent a user from being 'hit' by a vehicle.

Social interaction opportunity

The interactive character controlled by the researcher (in what would be a clinician's role) is no longer standing on the street waiting to be approached. Instead, the character is seated next to the user at the bus stop. As discussed in Chapter 2, social interaction is a central concern in ABI rehabilitation and closely related to executive functioning (see Section 2.4.1). This thesis has argued that is important to create opportunities for social interaction in rehabilitation scenarios. Placing the interactive character in a fixed, seated position generates different initiation challenges (decision to approach, establishing and maintaining social distance) but must be in a scenario that corresponds to real-world settings. The bus stop scenario affords this opportunity and its potential as such was agreed with BIRT's Research Fellow.

Character control and independence of vocal responses

The 'clinician'-controlled character in Virtuality Street was originally designed to use microphone input, where responses could be tailored based on what the user was doing or saying (see Section 6.5). This afforded a great degree of flexibility, where the researcher in control (playing the role of the clinician) could initiate conversations and vary responses. There were drawbacks: it required concentration from the researcher to maintain a persona and generate appropriate answers. In the **Interactions with the character** theme, some participants in our lab-based study also recognised the voice of the researcher (see Section 7.5.1). Coupled with their awareness of the environment as being under the control of the researcher (see **Awareness of designer** theme, Section 7.5.4), this may have affected their behaviour or understanding of the world. As neurotypical participants with backgrounds in computer science, these participants may have been more or less willing to suspend disbelief, or to be inclined to view the environment as a deliberately designed construct. It is difficult as such to draw conclusions from this. However, that they were able to recognise the voice and attribute it to the controlling researcher was a concern. Clinicians are integral to the rehabilitation process, and service users spend a lot of time with a clinician who they are familiar and comfortable with. That familiarity was identified as a drawback of standard roleplaying exercises when we first looked at rehabilitation practices in earlier chapters. People such as those residing at BIRT hospitals may interact with these clinicians every day, growing accustomed to their voices and inflections, and be able to discern their moods and tendencies.

A benefit observed in community based assessments such as the MET is that service users are exposed to new people who they may feel less comfortable with, and need to employ strategies to communicating with them. This is executive in nature as it involves shifting away from the routine – familiar people who understand an individual's ticks and mannerisms – and towards more conscious and strategic methods of integrating with members of the community. Creating a level of separation between the clinician and the character under their control is therefore valuable for facilitating clinically relevant social interactions in community settings. To explore this further, we implemented pre-recorded responses using the researcher's voice, that a clinician could discretely use during a session.

To predict what responses might be appropriate, we collated some common utterances given by the researcher during the lab-based VS-MET. We also considered the updated task list and introduced responses that we thought could be of relevance to task #2: **"What time is the next bus?"**. The list of pre-recorded responses is below.

Hello.	Alright mate.	Do you live around here?
Uh huh.	Oh, okay.	What do you mean?
Yes.	No.	Why do you want to know that?
Where?	Why?	What do you want?
It's about 12:30.	The bus, why?	Where are you going?
In about 10 minutes.	What are you doing?	I don't know what you're talking about.

Table 8.1: List of pre-recorded responses for the clinician-controlled character.

Although our goal was to develop a clinician user interface that could be used to select these responses, we wanted to see these pre-recorded responses in action before investing development time. In the VS-MET Sitting Version, each response therefore corresponds to a key on the keyboard. For example, pressing the 'X' key has the character ask "The bus, why?". A one-page list of these mappings was created for the researcher and clinician to use.

Testing process

Before using the VS-MET Sitting Version with service users or clinical professionals, we spent time testing the changes detailed in this section. It was first demonstrated at a university open day with visiting students, which allowed for testing of robustness and to check that tasks could be completed.

A video from this open day shows participants attempting tasks and the researcher controlling the character. This sometimes produced exasperated responses from users: https://youtu.be/QxDqrmKDNfY (Virtuality Street, 2017)

The structure of this open day, where the researcher was required to run a session (listening to users and selecting appropriate responses) whilst talking to other visitors, was a useful opportunity to practice demonstrating the system and the feasibility of operating the pre-recorded responses.

8.3 Planning VR Demonstration Sessions

Our work with the Disabilities Trust's Research Fellow to define the VS-MET was a step in the iterative development of a virtual reality system. The purpose of this step was not just to incorporate design ideas based on domain expert input, but to prepare for a key activity in the pathway to clinical evaluation: the facilitation of feedback from service users and clinical professionals. The refinements described in the previous section were made in coordination with the Research Fellow to ensure that Virtuality Street were ready for use by these groups and could facilitate the feedback that we were interested in.

The gathering of feedback was an integral step in the agreed upon process for the exploration of new technology with BIRT and DT. This process, as laid out at the start of the project, involved a series of activities to immerse the researcher into the clinical domain, develop a virtual reality environment, and gather initial feedback from service users and clinicians who could eventually benefit as end-users. The end goal of this process, which falls outside of the scope of this thesis, is an evaluation of the impact of virtual reality environments on clinical outcomes. Feedback from relevant users is valuable in supporting a case for such an evaluation to take place.

To this end, we planned a feedback activity involving service users and clinical professionals at a BIRT hospital. This was planned in collaboration with DT's Research Fellow, who had oversight on our interaction with BIRT and whose role was to ensure compliance with BIRT/DT processes. As such, the work we intended to carry out in a hospital was subject to review and revision by the Research Fellow. This was done by preparing an application to the Disabilities Trust's Research Ethics Committee (Appendix B). As part of this, we prepared a detailed description of the purpose and proposed procedure for carrying out feedback gathering activities. This followed the BIRT/DT process for determining whether the scope of any proposed activity would require formal internal review. In this way, it was clear that our planned activities were a form of engagement and that did not require full review by the Disabilities Trust's Research Ethics Committee. The proposed activities fell into the remit of service evaluation/public involvement, as they were not by themselves capable of evaluating outcomes for clinical practice as would be expected by the clinical definition of research (see Section 1.6). Nonetheless, the details described in the application form were important in describing the procedures for service user and clinician involvement, and in determining how the researcher should engage with these groups and address issues.

Our proposed activity was deliberately described as a "demonstration". Whilst this is consistent with our iterative design approach, respect for the real-world hospital setting and variable effects of brain injuries on service users meant designing sessions that were responsive to the supervising clinician's advice. This precluded the use of a fixed set of steps. It was agreed that demonstration sessions for feedback could be advertised and run with service users and staff at a BIRT service. The focus would be on what people in these groups think of the system, whether they believed it was a platform they would engage with, what risks and benefits they perceived there to be, and some feedback on the information provided about the project. Feedback forms (Appendix D) were designed to facilitate open comments on these facets.

The application form was sent as a briefing document to the consultant neuropsychologist of the BIRT service where the demonstration was planned to be carried out. The consultant agreed to arranging the demonstration with service users and staff, and recommended that audiovisual recording equipment could be brought to assist with feedback collection. He selected a date when most of the clinical team would be on-site, and requested a poster to advertise the demonstration sessions.

8.4 Demonstrations with Service Users

8.4.1 Service Users

Three service users were selected by the consultant neuropsychologist to use Virtuality Street. Details of their injuries were not disclosed to us, but they were described as being near the end of their rehabilitation and being ready for discharge. This meant that they could act independently and had accessed community settings during their rehabilitation. The consultant felt that these service users were suitable to participate in the demonstration due to the advanced progress of their rehabilitation, where they would have opportunity to employ learned strategies and faced minimal risk to their recovery.

Demographics on the service users were not collected due to the informal nature of the demonstration. However, each service user was described as having their own set of impairments arising from their injury. We report any disclosed traits here to set the context for their behaviour in Virtuality Street and comments about their experiences.

Service User 1 (SU1) was described as socially inept and having poor memory. **Service User 2 (SU2)** was said to have a tendency to panic and to "lose her cool with people", as well as to struggle with written words and verbalising language. SU2 also

Figure 8-4:
The room used for demonstrations at a BIRT service. The wall-mounted monitor was used to mirror what users saw in VR.

had an insight deficit that was different to the type we had learned about previously (see Section 2.3); she frequently thought that she had performed poorly at something she had done well in, and talked down her abilities. **Service User 3 (SU3)** was described as being the least impaired and ready to live independently, but had continuing vestibular and visuospatial perception difficulties.

8.4.2 Demonstration Procedure

Demonstrations took place within a BIRT service in one of the visiting rooms, which was given over to the researcher to use (Figure 8-4). A chair was placed in the centre of the room for users to sit on, and was positioned so that they would be sat at the VS-MET's bus stop. A wall-mounted monitor mirrored what users saw in virtual reality, which enabled the researcher and other interested parties to see what was happening in the environment. A couch and an armchair were already in the room, which observers could use to watch.

Demonstrations with the three service users took place consecutively on a weekday morning. The consultant took charge of locating each service user and inviting them to attend the demonstration. Although our planned procedure was that the researcher would brief service users on the activity, the consultant again took the lead in explaining to each person what the purpose of the demonstration was and asking if they would like to try the environment. The researcher then explained that they would be at a bus stop with a task list, using the wall-mounted monitor to illustrate, and would be asked to find the answers around them. They were shown the task list and told that they could talk aloud if they wanted to speak to anyone in the environment.

The researcher explained how to put on the virtual reality headset and use the controller, and told users to remove the headset or announce if they felt uncomfortable at any time. Each service user was given the headset and was able to put it on unaided. The researcher checked with the service user that they were comfortable or would like the headset adjusted before continuing, and then passed them the controller.

Although the procedure for the three service users began in the same way, it deviated as the session continued and the consultant saw opportunities. We describe these in the following sections.

Sessions with service users lasted 15-30 minutes. Written feedback was not collected from any of the service users, but each session concluded with a brief discussion between the researcher, consultant and service user.

No emphasis was placed on the service users' performance in Virtuality Street. Although the researcher made a note of which tasks had been completed, the consultant did not want the service users to focus on their performance in the environment on their first use of it, and was instead interested in seeing what behaviours could be observed from their attempts.

8.4.3 Service User 1 (SU1)

SU1 was described as having social difficulties and poor memory. The researcher and consultant agreed in advance to ask repetitive questions through the character to see how SU1 reacted. One pattern that quickly became apparent was for SU1 to ignore the character:

> *SU1: What time's the next bus?*
> *Character: The bus, why?*
> *SU1: *Exasperated* What* ***time*** *is the next bus?*
> *Character: Why?*
> *SU1: *Ignores**

As the session continued, this strategy to ignore frustrating questions manifested itself again:

> *Character: Do you live around here?*
> *SU1: Nope I don't live round here.*

> *Character: Why?*
> *SU1: *Smiles and ignores* Sunday 11th November *to self, continuing with tasks**
>
> *Character: Do you live around here?*
> *SU1: Nope I don't live round here.*
> *Character: Why?*
> *SU1: Because I stay somewhere different.*
> *Character: Why?*
> *SU1: *laughs and finds the final task**

SU1 was able to find the answers to all of the tasks except for the time of the bus, which could only be obtained from the character. The consultant praised SU1 for completing the tasks, saying that it was excellent for his first time in the environment, and then asked the researcher how many tasks were on the list. Whilst the consultant and researcher were locating the task list and counting, SU1 immediately said "six" (correctly) and began talking about the one task he had not completed. There was a brief conversation about his interactions with the character, in which he expressed frustration at the character asking him questions instead of answering. Both the consultant and the researcher encouraged him to be persistent, but SU1 commented that he felt that he was just arguing with the character.

SU1 was very keen to move around the environment, asking twice if he could stand up and walk 1) around the bus stop or 2) down the road. Although we had planned to only use the VS-MET Sitting Version, the consultant decided that SU1 should try 'walking' around Virtuality Street by attempting the standard VS-MET (see Chapters 6 and 7). The key differences to the Sitting Version were that the task list was displayed on a wall (and could not be carried), that tasks were dispersed around the environment, that rule-based time pressures were present, and that a clock was mounted on a controller. The researcher cleared a space in the centre of the room and then briefed SU1 on how to use the locomotion technique and controller-based clock.

SU1 got used to the locomotion technique quickly and started moving around the environment. He read through the static task list and chose to start with the task to "Go to Barry's after 5 minutes and announce the time". SU1 visibly looked at the clock and then moved to the main street. Although he paused a number of times and appeared confused, he went up to the "Barry's" shop; although he did not say anything, he looked down at the clock before moving back to the poster.

SU1 then got stuck on the task list. He was reciting each task and commenting on them to himself, including noting that he had completed some of them before in the Sitting Version (e.g. where the post office was). At this point the consultant intervened and told him to focus on a single task that he had not seen before: to find out the collection day of the bins. SU1 walked around the environment for two minutes, staying on the footpath, until he came across a bin outside of a house. From this, he deduced that the bins were being collected today. With assistive prompts from the consultant, SU1 decided to look for someone to help. He ruled out two nearby characters using their phones, and then approached the researcher-controlled character. In the VS-MET, character responses were through microphone input rather than keyboard control (we had not anticipated using this version in the demonstrations, so no work had been performed on it since Chapter 6). The researcher used similar responses to the Sitting Version to have the character respond with questions, as before:

> *SU1: Do the bins get emptied today, do you know at all?*
> *Character: The bins, why?*
> *SU1: Cause I need them emptied.*
> *Character: Why, do you live around here?*
> *SU1: Eh?*
> *Character: Do you live round here?*
> *SU1: Sure do.*
> *Character: Oh, where?*
> *SU1: Just up there in *name of a local area*.*
> *Character: Ah my sister used to live there. Do you like it?*
> *SU1: Yes yes. *pause* Okay.*
> *SU1: *Pauses and looks at a nearby cat for around 10 seconds**
> *Character: Did you want something else?*
> *SU1: Eh just to get the bins emptied, what day do they get emptied?*
> *Character: Well, today.*
> *SU1: Is it today, good stuff.*

SU1 passed by the "Barry's" shop on the way back to the task list and murmured that he needed to check the time, before continuing. The consultant then asked whether he had completed the task he had been working on, and then prompted him to finish. After a short conversation about SU1's experience in the demonstration, the session finished after 30 minutes.

SU1 Discussion

As agreed with the consultant, the researcher played the controlled character to be frustrating, to challenge SU1's social interaction skills. During the VS-MET Sitting Version, SU1's strategy to ignore these frustrations and focus on the tasks worked to a point. He was able to obtain all of the information gathering tasks except for finding the time of the next bus, which could only be obtained through conversation. The researcher spoke to the consultant about this after the demonstration, and was told that not responding to questions was an example of behaviour he would expect to see from SU1 due to his deficits.

During the discussion midway through the demonstration, SU1 expressed frustration with the character's repetitive questioning: "You can't, you just argue with him." Although he correctly asked the character about the bus times, and initially engaged with the questioning responses, SU1 did not follow through by bringing the conversation back on track, or by asking the question again. In the discussion, SU1 thought that he had been asking the question repeatedly, which was not the case. The consultant and the researcher encouraged him to be persistent with the character, although SU1 was not convinced that this would work. When facing the character again in the VS-MET, SU1 employed this advice to ask the question a second time and bring the conversation back on topic. He was able to immediately try the advice from the consultant and researcher, and was consequently met with success in his task.

In addition to his social difficulties, SU1 was described as having memory problems. With respect to insight, these manifested themselves when he thought he had been asking questions to the character. The ability to witness the conversation first-hand was crucial in understanding the problem; in our observation of 'Adam' in Chapter 5, the clinicians could not hear his conversations and had no way of knowing how he was performing. SU1's memory difficulties may have clouded his recollection of the conversation, but the consultant and researcher could hear it in its entirety, acting as a prosthetic to his memory and offering advice accordingly. Having that awareness of the conversation also gave the observers an understanding of how SU1's impairments might be challenging his social interactions.

From a functional task perspective, SU1's memory problems presented differently. When the consultant was commending SU1 on doing so well for his first time in the environment, the consultant and researcher paused to find the task list and count up how many tasks there were. Without seeing the list, and without hesitation, SU1 correctly recalled that there were six tasks. When placed in the environment for the second time, SU1 had difficulty initiating the tasks but did read through each of the tasks in turn. He had encountered many of these in the Sitting Version and could recall the answers (from around 10 minutes earlier). For example, he immediately identified the street that he had been sat on, despite starting some distance away, and remembered its name and that the post office had been located there. Later on, despite being focused on another task, he passed the "Barry's'" shop and recalled that he needed to check the time. In this respect, he seemed to exhibit good memory for functional tasks and retained information. He also had a good grasp of direction and could find his way around Virtuality Street unaided.

However, SU1 did become stuck when faced with a set of tasks that he could not take with him. Because of this, the consultant intervened and told him to focus on a single task. At the end of the demonstration, as SU1 was talking about his experience, he said that he found it difficult to remember the tasks given. He added that he would usually use a memory aid to assist him in the real world, such as a notepad or his phone, which would be helpful in the environment. This aligns with the **Remembering is difficult** theme from our neurotypical volunteers (see Section 7.5.5), who suggested being able to carry a representation of the task list.

A noteworthy event occurred as SU1 was finding out what day the bins were collected in the VS-MET. He noticed that bins were placed along the street, and deduced from this that the bins were collected on that day. This is a novel strategy that only P11 had employed during the lab-based study (see Section 7.5.5), and was a clear instance of executive problem solving. This demonstrates Virtuality Street's capacity to expose instances of executive functioning through approaches to functional tasks.

SU1 was also not satisfied with having to stay seated. He stood up during the VS-MET Sitting Version and asked if he could walk around the bus stop, then said that he wanted to walk down the road. When he was placed in the VS-MET with the locomotion technique, he had no difficulties moving around the environment. However, SU1 did frequently turn to look around, prompting the researcher to adjust the headset's cables lest he became tangled. The consultant noted that SU1 had stayed on the pavement when moving around, avoiding the street except when crossing. This is in contrast to many of the participants in the lab-based study who had strayed onto the road in the theme **Awareness of designer** (see Section 7.5.4).

At the end of the session, SU1 commented that he was hot: "It makes you sweat, it's like an oven" and needed water after removing the headset. However, he described his experience as positive, comparing it to some video games he had played at the service, and asking if the VR set could replace the service's game console.

8.4.4 Service User 2 (SU2)

SU2 was described as having speech and language difficulties, as well as having a tendency to panic and to get upset with people. These speech and language impairments were difficulties formulating sentences, selecting the right words, reading, and verbal comprehension. She also had a deficit to insight that was different to the kind that we had learned about before; SU2 frequently thought that she had performed poorly at something she had done well in, and she talked down her abilities.

The researcher and consultant briefed SU2 on what the demonstration would involve, and needed to re-iterate. The consultant took care to emphasise that there were no right or wrong responses, and that the purpose of the demonstration was to find out what she thought of the environment. When she was told that she could talk to people, SU2 expressed concern:

> *SU2: Because of my injury and things I forget things, so I would need to be told exactly what to say because... I'm not good at saying things properly... I'm not the best.*
> *Consultant: Your speech is a lot better than it was initially, and this is why we have the list on the paper so you can see what's to do. *demonstrates with the task list by showing it on the monitor**
> *SU2: Right... So I would have to read that? That's where I might go a bit run... wrong.*

SU2 was a glasses wearer and kept these on underneath the headset. When she put the headset on, she commented excitedly that the glasses were enabling her to see. However, she quickly went on to struggle with reading the task list. The researcher was concerned that the headset may not be positioned correctly and was thus presenting a blurred view, so suggested raising or lowering the headset until it was in focus. SU2 repositioned the headset and then held it with one hand, continually raising and lowering it as she read. However, she still had difficulties reading:

> *SU2: I'm not very good at eating... reading things properly. 'What street is the post... office on'... is that what I've said?*
> *Consultant: Yes, that's right.*
> *SU2: 'What street is the...post office on... What time is the...next...bus?'*
> *Consultant: That's it.*
> *SU2: 'What time is post...clock?'*

> *Consultant: I know you have a bit of difficulty reading, so I could read out those things for you.*

The consultant then assisted SU2 by reading out the task list and checking that she understood, before prompting her to look around the environment or talk to people to search for the answers. SU2 was still struggling after this, so the consultant told her to try the first task and read it out to her again. She identified the post office further down the road and was prompted to look for a clue as to which street she was on, and quickly spotted the street sign opposite. Although she had difficulty reading the sign, SU2 did get it correct after an initial mistake.

SU2 spent several minutes on the second task, which involved finding out the time of the next bus:

> *SU2: Which time is the next bus... Do we have a bus? Do we have a bus?*
> *Consultant: You're at a bus stop.*
> *SU2: Did I? *looks around* A bus stop... I'm useless at this. There's somebody standing over there, there's a woman, is she waiting for the bus? I can't see any bus *laughs*.*
> *SU2: *looks around the environment for 20 seconds, then sees the 'Bus Stop' road markings in front of the bus stop**
> *SU2: I'm sitting on it! I am! Sorry, now I've just realised. We are now standing on the bus! On the other door... the other store... car... it says it there *points to 'Bus Stop' markings*.*

During this time, SU2 had been looking around her surroundings, which included looking at the controlled character sat next to her. The researcher attempted to initiate conversation whenever SU2 was looking at the character, using phrases "Hello" and "The bus, why?", but SU2 did not seem to hear them. After discovering the 'Bus Stop' markings, the consultant prompted SU2 to ask the person next to her for help.

> *SU2: Is there a bus coming?*
> *Character: The bus, why?*
> *SU2: 'The bus, why?' Does it say? *starts looking around and reading the poster*. No, I'm losing it I'm afraid.*

The consultant suggested removing the headset after this, and SU2 agreed. The session concluded with a 5 minute conversation about SU2's experiences, with the demonstration as a whole lasting 15 minutes.

SU2 Discussion

SU2's speech and language difficulties were an obstacle to her use of the environment for the tasks.

Reading was perhaps the most notable of these. SU2 announced early on that she was struggling to read the task list, and she moved it closer to and further from to try to bring it into focus. The researcher was concerned that the headset may not be worn correctly and suggested adjusting it, but this did not seem to make any difference. There may have been multiple factors at work here. Most pertinent would be the reading impairments themselves, which may have hindered SU2's reading of the tasks. This was certainly something described to us and identified by both SU2 and the consultant as a problem for her. Secondly, SU2 was a glasses wearer and kept these on underneath the headset. We did not ask for details of her prescription (e.g. whether she was short- or near-sighted, or used bi-focals) at the time, as this realisation only came afterwards. This may have contributed to difficulties, for example if SU2 was using bi-focals for reading, but we have no further information on this; nonetheless, it must be noted. Quality of the text in the environment may also have been a factor – this was identified in the theme **Fidelity as a cue** (see Section 7.5.4) where some of our lab-based participants struggled to read smaller characters. SU2 may also have struggled to adjust the headset until it was correctly positioned and brought objects into focus – due to deficits to insight, she may have assumed that her reading impairments were to blame rather than persist with making adjustments. Whilst attempting to adjust the headset, SU2 was repeatedly saying that she was the wrong person and "rubbish" at using it. Any one or combination of these factors may have contributed to the difficulties reading.

The consultant began by encouraging SU2 to read the first two tasks, and then stepped in to act as an aid by reading them for her. SU2 was able to quickly identify the building marked 'Post Office' and the street sign, demonstrating that her vision was not entirely impaired. This highlights the complex nuances of impairments that we may simply not be able to appreciate as HCI researchers with moderated information about a service user and their injuries. We may oversimplify a visual impairment by assuming generally blurred vision, when it could be particular to text. A clinician with an understanding of the specifics of an impairment is crucial to determining the suitability of tasks for individual users and interpreting their resultant behaviour accordingly.

Hearing ability was also a contributing impairment to engaging with the environment. During the open discussion about her experience, SU2 disclosed that she could not hear out of one ear. This was said to be a recent impairment – which is why the consultant had been unaware – and it was unknown whether it was related to her injury. During the demonstration, the researcher attempted to initiate conversation with the controlled character. When this did not work, the researcher supposed that she was mistaking this for background noise, and he began waiting until SU2 was facing the character so that she could see the visual cues of the character talking. It was only when she was prompted by the consultant that SU2 initiated conversation with the character. When the hearing impairment was disclosed, the consultant realised that the character was sitting on the side of her deaf ear, and suggested that this had prevented her from hearing the character properly. This was recommended to be screened for.

The consultant also suggested that phonological or prosodic features of speech could play an important role in SU2's understanding of the character. He noted that her language skills had improved considerably during rehabilitation, where she had initially struggled to understand people, but that maybe she was not yet ready to understand someone speaking short sentences in an "unusual accent" – the character's phrases were recorded by the researcher, who comes from the south-east of England; SU2 came from a different part of the country. Although this did not seem to be an obstacle (since SU2 seemed to have no difficulties understanding the character, but instead seemed not to hear him), it remains an important point for us to consider.

SU2's speech impediment – where she might use the incorrect word in a sentence – was present during the demonstration. The consultant noticed that this was much more prevalent when using Virtuality Street. We only noticed one instance of SU2 substituting the wrong word during the discussions, when she used the word "run" instead of "wrong". In contrast, this occurred multiple times when in Virtuality Street and was more pronounced, for example replacing the phrase "bus stop" with "the other door... the other store... car". This suggests that something about the situation (being in an unfamiliar place, performing non-routine tasks, using unfamiliar technology) brought out this impairment in a more pronounced way. Although the impediment was an obstacle to understanding SU2, it was not insurmountable – she sought to correct herself and the researcher could understand her intention from the context. However, it could still be useful for a speech and language therapist to see these instances of behaviour, especially if they are indeed more prominent than usually encountered within the familiar service.

Generative thinking for dialogue was more of an issue for SU2. She expressed concern at the start of the session that she would "need to be told exactly what to say" if talking to someone in the environment. This was reflected when she initiated conversation with the character:

> *SU2: Is there a bus coming?*
> *Character: The bus, why?*
> *SU2: 'The bus, why?' Does it say? *starts looking around and reads the poster next to her for several seconds*. No, I'm losing it I'm afraid.*

SU2 could not formulate a response to the character's reply, which deviated from the question-answer norm of dialogue that she may have expected. This is an executive problem that we have seen before, such as with 'Adam' in Chapter 5 (Greeting: "Hello", Response: "No", Section 5.6.1), or when clinicians tried our bus prototype in Chapter 4 (Statement: "I'd like a ticket please", Response: "No", Section 4.5). SU2's plan was to ask a question and receive an answer (e.g. "In 10 minutes"), but the character's response did not to conform to this, and she could not reformulate the plan. This demonstrates that interactions within Virtuality Street have the potential to draw out these instances of plan error, which could be useful for assessing or practicing such situations.

SU2 said throughout the session that she was the wrong person to be trying Virtuality Street, suggesting that other service users would be better at it. The consultant encouraged her throughout, such as praising her reading or reminding her that the demonstration was to get her feedback. SU2 said that she enjoyed the environment and was impressed that she could look around, but that she thought other service users would get more out of using it – as before, she made reference to what she felt was poor performance on her part. The consultant encouraged her and suggested that some users may benefit from a different use of the environment:

> *Consultant: Do you think this would be useful for people to practice picking things up in the environment? Because you started looking around and really taking in a lot.*
> *SU2: I could see everything, it was really good, but any of the other people I think they'd love it. They would do better than I would definitely, but it was actually good, I really enjoyed it.*
> *Consultant: The first time doing anything is going to be strange, especially with other people in the room. But when you were practicing your reading, which is useful rehab, and then answering the questions from the environment, you seemed to get quite a thrill out of getting the answer right when you figured it out: "Ah that's West Street!"*

> *SU2: Yes! That took me a while *laughs*.*
> *Consultant: It doesn't matter how long it took, you did it in the end!*
> *Researcher: And when you saw the 'Bus Stop' sign on the road.*
> *SU2: *excited* I know! Now that took me a while.*
> *Researcher: You're the only one who's seen it, or said aloud that you've seen it.*
> *SU2: Oh!*

Although her speech and language impairments impeded the information gathering tasks, there may still be benefits from using the environment to practice searching an environment. Doing this more informally (i.e. without tasks) may also be a more appropriate activity for someone with this type of insight, who may feel that they are doing poorly and need careful management of understanding what is expected of them. Removing that formality could reduce the service user's focus on how badly they think they are doing, and enable them to focus on the "thrill" of finding something.

8.4.5 Service User 3 (SU3)

SU3 was the "least impaired" of the three service users and was said to be ready to live independently, but she had continuing visual, visuospatial perception, and mild vestibular difficulties. SU3 had tried a virtual reality headset, belonging to a family member, before but said that this had only been brief. She could not remember which headset.

SU3 began by reading the first task out loud and answering it without pause, despite (from what could be seen on the monitor) not moving her focus from the list. On the second task involving the time of the next bus, she again did not pause but proclaimed that she did not know, before standing up unprompted and turning to look around her. The researcher attempted to initiate conversation through the character ("Hello") which SU3 laughed at and ("What are you doing?") responded by verbalising her thought process. She announced that she was looking at the poster next to her for some indication of the time, and then stated that it should be on the board on the bus stop – this is normally where a bus timetable would be found in the UK, but had been replaced in the virtual environment.

After passing on the bus task, SU3 moved to the next task (**What time is post collected from West Street on Saturdays?**). Although the answer to this could be found on the post box next to where she sat, she seemed to misunderstand the task. SU3 looked at the post office across the road for several seconds before asking:

> *SU3: I know this is a stupid question. I can see the post office but I can't see what time it's open. Am I allowed to cross the road?*

The researcher and consultant agreed to this and she was shown how to use the locomotion technique using the controller's touchpad. She moved forward to the edge of the road, looked both ways ("Check I'm not going to get knocked down") and crossed towards the post office. She also started moving with her feet and asked if she was going to hit anything, so the researcher and consultant stood by her side to reassure her and prevent her from hitting objects around the room. She remained standing/moving throughout the rest of the session, but twice stepped outside of the bounds of the Vive sensors and had to be brought back towards the centre of the room. The observers also had to frequently intervene as she kept trying to walk into the armchair and sofa in the room. On several occasions she could not move due to virtual objects, such as bollards, being in her way which she did not notice, and needed prompting to avoid them.

By moving around the environment, SU3 was able to find answers to two more tasks, but missed the answers available at the bus stop.

When SU3 removed the headset, she said that she felt slightly disoriented returning to the real world but quickly felt normal again. As before there was a brief conversation around her experience, and the demonstration finished after 10 minutes.

SU3 Discussion

SU3 was said to be the least impaired of the three service users, being almost ready for discharge and having practiced returning to independent living. She was described as having visual, visuospatial and mild vestibular difficulties.

The impact of SU3's visual impairments was indirect – she thought that they hindered her performance but they did not. When she first put the headset on, SU3 was able to read the task list clearly and without error. She answered the first question (**"What street is the post office on?"**) without pause. SU3 did not look around when she put the headset on, instead facing forward towards the post office and street sign on the opposite side of the road, and seemed to have retained this information. However, later in the session SU3 felt hindered by her visual impairment. She asked to cross the road in order to see what time the post office was closing. When she reached the post office, she stated:

> *SU3: "I'm totally blind honestly, I think I'm the wrong person because all I*

Figure 8-5:
The exterior of the post office that SU3 attempted to read. No information is intended to be found from the low resolution window texture.

> *can see is colours mushed together."*

This contrast, where her vision had worked well at the start of the session but now seemed to hinder her, was perplexing. At the time, the researcher was not looking at the screen and was instead ensuring that SU3 would not become tangled in the headset's cable. It was only afterwards that he realised that she was looking at the exterior of the post office, which consisted of low resolution images that were not intended to be interacted with (Figure 8-5).

In our lab-based study, these low resolution images were identified by participants as being unimportant background images, as recorded in the theme **Fidelity as a cue** (see Section 7.5.4). They meant that participants had discarded the images' owning buildings as ambient shops that had no relation to the tasks. For SU3, the blurred image of the post office window was perceived to be a personal deficit rather than a design feature of the environment. She apologised during the end-of-session conversation that her vision had got in her way, but was profusely reassured by the observers that the environment was imperfect and not all images were clear. As the consultant put it: "It's not all you." This tendency to blame one's own deficits must be considered and managed.

When moving around the environment, SU3's visuospatial difficulties showed in the form of her getting stuck on objects, such as benches or bollards. These were generally low-positioned objects that would not be in her foveal view. The researcher prompted her to move whenever this happened. Otherwise her impairments did not seem to impede her; a clear compensatory strategy being used was to turn until objects were more towards the centre of her vision.

More interesting was the elective behaviour SU3 exhibited with moving around the environment. She immediately stood up when searching the bus stop; this may have been a necessary behaviour with the above compensatory strategy to bring objects into her foveal vision. The chair that she was sat in had arms and did not easily afford its user twisting to directly look at objects beside or behind them.

SU3 also wanted to move around the environment. When standing, she physically moved around the chair to get a better look at the bus stop around her. Afterwards she wanted to move further. This desire came from an apparent misunderstanding of her task, which she interpreted as finding out what time the post office closed. Since this was not a task in the VS-MET Sitting Version, the information was not visible from her sat position, so she believed she needed to move around to find it. Even after visiting the post office, SU3 continued to move around the environment. Although she had been taught to use the touchpad controls to move, SU3 combined this with physically walking around the room. The consultant found these behaviour encouraging:

> *Consultant: It showed to me that you were really engaged with it, because you were actually trying to cross the street and look at signs. ... Another way of using it is to use [the controller] but in your case you were actually doing the walking which was great.*

However it did present a problem. The walkable space in the room was relatively small (around 3m x 2m) with objects around the side, such as a table and chairs. SU3 frequently moved towards the edge of this space and had to repeatedly be stopped and brought back. Although her behaviour was seen as a positive and reflected engagement with the environment, it was very much constrained by the size of the room.

Another elective behaviour was using road safety strategies to cross the road, where SU3 stopped to look both ways before crossing, and paused to wait for an oncoming car to pass. She said that that this was a behaviour practiced with the occupational therapists when she went out into the community. This demonstrates that learned skills can be brought by service users into Virtuality Street.

Although she had a mild vestibular impairment – further details were not disclosed – SU3 had no difficulties when standing up or walking around. When she removed the headset at the end of the session, she commented that she felt disoriented, but this quickly subsided.

SU3 described the experience positively and identified value in Virtuality Street:

> *SU3: I can understand why you would do it, to help people when they come out of hospital or this kind of place.*

8.4.6 Service User Demonstration Summary

The demonstration sessions reported in this section were the first time we had access to service users to use Virtuality Street. Their purpose was to see how these service users engaged with the proposed technology as a step towards the ultimate goal of clinical evaluations for uptake in routine practice. The sessions provided us with feedback and considerations about service user engagement with Virtuality Street.

Clinically relevant behaviours

For each of the service users who used Virtuality Street, we observed behaviours that reflected their individual impairments. **Service User 1** had difficulties interacting with a challenging character, and his memory/insight led him to think that he had been employing a socio-cognitive strategy (asking questions and persisting with them) better than he had. **Service User 2**'s speech and language impairments led to difficulties with reading, verbal and visual comprehension, and speech. Her executive impairments showed as problems with generative thinking and recovering from plan error, as well as negative insight about her performance. **Service User 3**, the “least” impaired and near the end of rehabilitation, had some difficulties avoiding obstacles due to a visuospatial impairment, and an insight issue emerged where she though that her visual impairment was hindering her performance. The attending consultant supported these observations for each service user, noting that their individual deficits had become apparent during the sessions.

Our observations do not attempt to quantify the extent to which each person's impairments affected their performance. A future goal of clinical trials would be to use Virtuality Street for the assessment of functional and socio-cognitive behaviours, and this would likely involve some to-be-determined metric to describe the extent to which impairments manifest and can be observed. Within the immediate scope of this thesis, our demonstration sessions suggest that Virtuality Street is capable of exposing clinically relevant behaviours and impairments to be observed and reported for clinical use.

Clinical virtual reality session in action

Our expectations of how a virtual reality session could take place have been driven by theory and exposure to current practice. In Section 4.4.1 we presented a storyboard developed through our understanding of a typical rehabilitation session through literature. In Chapter 5 we learned about how sessions take place within a rehabilitation centre (see Section 5.3) and in the community (see Section 5.5).

In these demonstrations, we previewed what a virtual reality session might look like in routine clinical practice, as a product of tasks afforded by Virtuality Street and interactions between a partaking service user and a clinician. Each service user was given a set of tasks to complete in Virtuality Street – in the VS-MET Sitting Version, these were information gathering tasks with a socio-cognitive element. The consultant, as the clinician for these sessions, intervened as needed. This included changing the task list, such as by telling SU1 and SU2 to only do a specific task. It also involved commenting and prompting. A prompt for SU1 demonstrates the type of intervention that might be used: "The bins are out, good solution. What day is it do you wonder? You could see if there's anybody about, anybody you could ask". For SU2 it meant affirming what she was reading aloud and helping with reading.

The frequency and intensity of clinician involvement also varied between service users. For SU2, the clinician let her begin the tasks alone and then quickly intervened when she was struggling. He then sat next to her for the rest of the session to give significant support: helping her with reading, prompting her on tasks, and giving her encouragement. For SU1, the clinician observed his performance and then gave occasional prompts in the second half of the session. For SU3, the clinician took a hands-off approach and observed without intervention – a stark contrast existed in the room where he silently sat back on the sofa to watch SU3, compared to sitting alongside SU2 and actively talked her through the session. This variety of involvement is in line with our understanding of clinical practice built up through previous chapters, where we have noted degrees of prompting used for people of differing levels of functional independence. In fact, the frequency and timing of prompting was found to be a relevant measure in the scoring and reporting of clinical assessments (see Section 5.3.3).

Benefit of review and repeatability

As part of our literature-driven storyboard of a virtual reality session (see Section 4.4.1), we envisioned that a service user could attempt a task in the environment, discuss and reflect upon it with a clinician, and then attempt the task again armed with strategies or suggestions on what to do differently. During the demonstration session with SU1, we observed such an exercise take place. SU1 initially struggled with communication with the controlled character, and discussed this with the researcher and consultant after removing the headset. It was suggested to him that he should be more persistent with the character. When he accessed Virtuality Street for the second time, he demonstrated this persistence by bringing the conversation back on topic. This further illustrates how a virtual reality session could be routinely used to facilitate practice.

In Section 3.5.3 we described some theoretical considerations of community-based activities, and identified repeatability as a drawback. For instance, if service users wanted to practice a particular activity or interaction, it takes time to move them to an appropriate setting, and then the situation may not be easily repeatable. The circumstances of the situation may change, or a particular person may not be present to interact with again. We observed this in the community-based MET (see Section 5.6.1) when the service user "Adam" had an unusual social interaction with a member of the public; it would be difficult to naturally encounter this situation again. SU1's experiences with the controlled character demonstrate a benefit to Virtuality Street in the repeatability of particular encounters that deliver socio-cognitive challenges.

Benefit of playback

Playback was used extensively during the lab-based study reported in Chapter 7, where participants were asked to watch themselves back to make remarks about the environment, their reasoning, or their performance. In the demonstration sessions, we did not use such playback with service users and there was no emphasis on their performance. However, there was value found in looking at the environment on the monitor during the end-of-session discussion. For instance, to look at a shop sign when a service user asked where the information could be found. For SU3, there was inadvertent value found when showing her blurred images within the environment; this reassured her and corrected her perception that her own vision was to blame.

Space constraints

Participants were not expected to move around the environment during the demonstration. SU1 was keen to stand up and physically move around, and the consultant subsequently allowed him to use the VS-MET (with controller-facilitated locomotion) to move around. SU3 stood up to explore her immediate area to find information around the bus stop, and eventually asked if she could cross the road; she was similarly shown how to use the controller but she voluntarily coupled this with physically walking around. Both SU1 and SU3 were able to use the locomotion technique, but SU3 in particular would revert to taking small steps when she wanted to get closer to an object.

The size of the room used was a significant constraint on physical movement. SU3 exemplified this, as she frequently moved towards objects in the room and needed the researcher or consultant to guide her. We must note that the demonstration sessions took place in a room typical of those found in BIRT services, with furnishings befitting its day-to-day purpose. The constraints on moving around such a room need to be recognised, as any virtual reality setup would have to be deployed in a room which may have multiple uses in day-to-day operations of a service.

Accents and nuances

The researcher conducting the demonstration sessions comes from the south-east of England. The service users taking part all came from a different part of the country. Regional accents were at times difficult to understand from both parties – the consultant suggested that understanding the researcher's accent was a hindering factor during SU2's session. This suggests the importance of involving a clinician who is familiar with the service user and who has spent enough time with them to be comfortable with accents or phrases. However, this may also be a problem. The consultant was able to understand some utterances despite being incomprehensible to the researcher, but the researcher may be a closer approximation to a random person encountered on the street. Clinicians spend time with service users and learn their mannerisms, sayings, and ticks, which may be lost on someone unfamiliar to them.

Although prosody and phonology did not seem to be an issue with SU2 – her difficulties seemed to come from trouble hearing the researcher-controlled character, rather than understanding him – this is still an important point. Service users may practice regaining communication skills with speech and language therapists with particular accents, but may struggle when encountering others.

Testing component skills

The demonstration sessions revealed that there is value in testing component skills (e.g. reading, finding something in the environment, road safety), as alternatives to a more complete task that requires putting these components together and managing them. This was highlighted with SU2, who found it difficult to complete the tasks. It was suggested that it could still be useful practice for her to read or identify elements of the environment, such as a sign or road markings. This was further demonstrated with SU3, who exhibited her road crossing strategies that she had been practicing with therapists.

Interpretation of design features

Virtuality Street contains a number of low-resolution images as textures. To assist in development time, these were used as ambient textures on objects that are not involved in tasks, such as a shop window. Participants in the lab-based study interpreted these as unimportant background images in the theme **Fidelity as a cue** (see Section 7.5.4). In the demonstration sessions, service users took a different interpretation, where they assumed that the images were correct but that their impairments were to blame. This is a risk for people with negative insight who may feel that they always perform poorly, or people who may be left with negative feelings about their impairments and rehabilitative progress. The consultant and researcher were able to pick up on this during the session and show service users the low-resolution images on the monitor, clearing up that confusion, but could have been easily missed. This risk needs to be managed either by better design and implementation, or through systematic explanation and reassurance.

Importance of clinician involvement in next steps

During the demonstration sessions, service users did or said things that we would be interesting to ask about and explore further. The researcher did not always think of these at the time, and sometimes the service user moved onto another topic before it could be discussed. Once the session had concluded, service users resumed their daily activities and could not be accessed for follow-up questions.

In future work to evaluate Virtuality Street for routine clinical use, it is critical that in-house psychologists are involved and conduct sessions with service users. Their access to service users would enable these follow-ups to take place, and to conduct multiple sessions so that adequate time can be spent gathering feedback and evaluating the environment.

This is also true for the level of information brought to the session that informs understanding of service user behaviour. We were provided with filtered information about service users, with broad descriptions of their impairments. When making sense of how they used the environment, we did not always know enough – clinicians with familiarity with a service user are better placed to do so.

8.5 Demonstrations with Clinical Professionals

This chapter is reporting on user engagement activities conducted as part of the overarching user-centred design approach that this research has taken. The sessions with service users reported in the previous section were used to gather feedback on how they engage with Virtuality Street and virtual reality technology.

Clinical professionals are the people ultimately responsible for the prescription, administering, recording and interpretation of therapeutic tools in the day-to-day operations of a rehabilitation service. Throughout the work reported in this thesis, we have worked with clinical professionals who are advocates of virtual reality in brain injury rehabilitation. These people have facilitated our work within BIRT services and informed our understanding of clinical considerations that need to be met when working with this population. To improve the validity of this design work and to support the case for clinical evaluations to take place in the future, we ran demonstration sessions with clinical professionals without prior connection to the project. The purpose of these demonstrations was to gather their feedback on usability and acceptability of the technology, but also to understand what benefits and risks they might see in the project, and whether pathways exist to overcome these risks that could be considered in our design work and further iterations of Virtuality Street.

In this section we report on demonstration sessions with two groups of clinical professionals: the first from a BIRT service, the second from a specialist (non-BIRT/DT) hospital.

8.5.1 Clinical Professionals

Two groups of clinical professionals were involved in demonstration sessions of Virtuality Street.

The first group consisted of staff at a Brain Injury Rehabilitation Trust service. 11 staff participated in demonstration sessions over a three day period, by using Virtuality Street, observing others using it, or by talking with the researcher, and then completing feedback forms (see Demonstration Procedure, Section 8.5.2). The roles and relevant experience of these staff are shown in Table 8.2. Almost half of these participants were psychologists, who had worked in brain injury rehabilitation for between a few months to over 20 years. Other people involved in the day-to-day administering of therapeutic activities also took part: a speech and language therapist, a staff nurse, and rehabilitation support workers who would assist service users during the day and accompany them outside of the hospital. 2 administrative staff attended, who were

#	Length of time working in brain injury rehabilitation	Current role	Other roles or experience in rehabilitation
BIRT1	4 months	Assistant Psychologist	No
BIRT2	2 years	Rehabilitation support worker	Yes, multiple
BIRT3	Almost 5 years	SLT	Also worked at *** as an RSW
BIRT4	Just started	Staff Nurse	Elderly care rehab
BIRT5	5 years	Senior Clinical Psychologist	2 years - alcohol related brain damage rehab
BIRT6	21 years	Consultant in Neuropsych and Rehab	Support worker, assistant psychologist, clinical psychologist
BIRT7	1 year 8 months	Business Administrator	No
BIRT8	1.5 years	Unit secretary	No
BIRT9	4 years	Assistant Psychologist	No
BIRT10	8 months	Rehabilitation support worker	No
BIRT11	2.5 years	Assistant Psychologist	Nursing Assistant

Table 8.2: BIRT staff who provided feedback during demonstration sessions

#	Length of time working in brain injury rehabilitation	Current role	Other roles or experience in rehabilitation
HOSP1	7 years	Neuro OT	Several neuro rehab/accute units
HOSP2	8 years	Physio-Neuro	Yes
HOSP3	20+ years	Social Worker	No
HOSP4	5 years	Occupational Therapist	Other settings such as orthopaedics
HOSP5	6 months	Exercise rehabilitation instructor	Yes, within trauma and mild/moderate musculoskeletal rehabilitation
HOSP6	15 years	Physio	No
HOSP7	7 years	Band 7 Neuro OT	General rehab, mainly inpatient neuro rehab
HOSP8	3 years	Assistant psychologist	Rehab assistant
HOSP9	12 months	Exercise rehabilitation instructor	Primary care rehab, military based 7 years
HOSP10	1 year	Physiotherapist	Neuro, musculo-skeletal, repsiratory, ortho-physio
HOSP11	2 years	Physio	General medical rehab - 1 year
HOSP12	7 years	Occupational Therapist	-
HOSP13	2 years	OT	Older adults, stroke unit

Table 8.3: Specialist hospital staff who provided feedback during demonstration sessions

involved in the routine operations of the service. 5 participants had other experience working in rehabilitation. We refer to this group as the BIRT staff.

The second set of clinical professionals were a group of staff at a specialist hospital for members of a UK-based organisation. Amongst the injuries they were required to rehabilitate, acquired brain injuries (particularly traumatic in nature) were prevalent. 13 staff participated in a demonstration session and completed feedback forms. Table 8.3 shows the roles and relevant experience of these staff. The staff were predominantly occupational therapists and physiotherapists/exercise rehabilitation instructors. One psychologist and one social worker also participated. We refer to this group as the specialist hospital staff.

8.5.2 Demonstration Procedure

Demonstrations with the BIRT staff took place over a three-day period, during the same site visit used for demonstrations with service users described in this chapter. The demonstrations used the visiting room described in Section 8.4.2 (Figure 8-4).

Staff at the BIRT service were advised in advance by the consultant neuropsychologist that the researcher would be visiting with a demonstration, and advertisement posters were placed around the hospital. All staff were encouraged to engage with the demonstrations during the site visit. Staff visited individually or in pairs/groups. Engagement consisted of using Virtuality Street, observing a colleague using it, or talking to the researcher about the project. Demonstrations with each staff member/group of staff varied in length from 15 minutes to over one hour. Those using Virtuality Street were in the environment for between 5 and 10 minutes, with remaining time spent in briefing or discussion.

Demonstrations with specialist hospital staff took place on a 1 hour visit to the hospital, on invitation of an occupational therapist there. Staff were invited to attend a presentation by the researcher and academic supervisor of this thesis, who presented the rationale for the project and the grounding in observed BIRT clinical practice that had informed the iterative design work. The purpose of this presentation was to elicit trust that the realisations of this project had been developed with a clinical practice-centred approach and through input from domain experts. It was also to present our understanding of clinical practice to a non-BIRT audience and to ask them to challenge that view if it did not fit with their own practice.

The visit, comprising of the presentation and demonstrations with specialist hospital staff, took place in a lecture room in the hospital. A photograph of the room was not permitted. The virtual reality kit was set up at the front of the room and a projection screen was used to mirror what users were seeing for observers. A chair was positioned so that users would be sat at the VS-MET's bus stop. Following the presentation, specialist hospital staff were invited to try Virtuality Street, observe others using it, or to discuss the project.

Staff from both groups of clinical professionals were asked to complete a feedback form about Virtuality Street (Appendix D) to gather feedback on the perceived appeal, drawbacks, and usability of the system, and to inform the provision of information to be provided to clinical professionals in future work.

8.5.3 Clinical Professional Feedback Discussion

The feedback forms given to clinical professionals during demonstration sessions were used to gather information about the professionals' experience and feedback on the appeal, drawbacks, and usability of Virtuality Street.

Demographics

Staff were asked about their roles and relevant experience, which were used to describe the demographics of people involved in these sessions (see Section 8.5.1). The demonstrations attracted professionals with a variety of specialties and experience. BIRT staff were largely psychologists responsible for the prescription of rehabilitative programmes and administering of neuropsychological tests, supplemented by staff involved in the day-to-day operational care of service users. Specialist hospital staff were typically occupational therapists and physiotherapists/exercise rehabilitation instructors, who would be more involved in the practical preparations for returning a service user to daily living activities. Both groups included people with rehabilitation experience beyond their current roles, such as elderly care and musculoskeletal, as well as the stroke and neurobehavioural rehabilitation focused upon in this thesis. The diversity of these participants is highlighted as each clinical professional's insights around a virtual reality tool will have been shaped by their experiences and priorities in discharging their duties. In this section we do not analyse how staff of particular roles or backgrounds respond to Virtuality Street, but we do approach the feedback acknowledging its multidisciplinary origins.

Familiarity with brain injury models

Our understanding of the clinical problems to be addressed in this thesis have involved a conceptual understanding of executive functioning, primarily formed through the

#	Familiarity with CMEF by Sohlberg and Mateer	Other models of executive dysfunction and brain injury
BIRT1	Yes	No
BIRT2	No	Unsure
BIRT3	No	-
BIRT4	No	No
BIRT5	Yes	-
BIRT6	Yes	Baddeley 1996; Norman & Shallice 1980; Stuss 2012; Neurovehavioural model (e.g. Wood 2001)
BIRT7	No	No
BIRT8	No	No
BIRT9	Familiar but not well	Neurobehavioural model
BIRT10	Yes	-
BIRT11	Yes	-
HOSP1	No	Cognitive Hierarchy
HOSP2	-	-
HOSP3	No	No
HOSP4	Yes	-
HOSP5	No	No
HOSP6	Vaguely	Many different models for physical and vestibular rehab
HOSP7	No	Model of Awareness
HOSP8	No	Neurobehavioural model
HOSP9	Yes (minimal)	No
HOSP10	No	No
HOSP11	Yes	No
HOSP12	Yes	[CMEF] is sufficient
HOSP13	No	-

Table 8.4: Clinical professionals' familiarity with models used in the rehabilitation of brain injuries

clinical model of executive function by Sohlberg and Mateer (2001). To inform how information about the project may be presented to clinical professionals, we asked staff about their familiarity with models to describe executive functioning or brain injuries. 6 BIRT staff and 5 specialist hospital staff reported at least some familiarity with the Sohlberg and Mateer model. 1 BIRT staff member described other theories of executive functioning, such as Norman and Shallice's (1980) Supervisory Attentional System (see Section 2.3). The Neurobehavioural Rehabilitation Model was identified by a participant from both groups, which we have theoretically known forms the foundation of many rehabilitation practices, particularly BIRT (see Section 3.4). Other models were identified which were previously unknown to us – Model of Awareness and Cognitive Hierarchy – which should be looked at in future work. The use of relevant conceptual models and language from multiple rehabilitation disciplines may be helpful in future communications around Virtuality Street and supporting engagement and buy-in from clinical professionals.

#	Do you see any potential utility for this platform?	What could you learn about service users and their behaviour by using this platform?	Is this a platform you would engage with?
BIRT6	Enabling people with limitations or community access restrictions to practice skills	Co-ordination of complex activities; interpersonal interactions; navigation under constraints (e.g. road safety)	Yes
BIRT9	Assessment; training; practice; gradual exposure to difficult situations. Would be interested in how behaviours in VR translate to predict behaviours in real life.	Response to challenging situations to minimise risks, e.g. lots of SUs get agitated in busy environments	Yes
HOSP5	Enabling people with limitations or community access restrictions to experience situations	Reactions to situations before trying them in real life	Yes
HOSP7	Feedback on errors; road safety; recording social interactions	Response to sensory stimulation; awareness of risk (driving, road crossing); social interactions; problem solving and self monitoring	Yes

Table 8.5: Clinical professionals' responses on the perceived benefits of Virtuality Street (Excerpt from Appendix E)

Perceived benefits

Throughout this project we have sought to understand how and why relevant activities are prescribed in clinical practice, in order to design a virtual reality environment that delivers benefits to those involved in the rehabilitation of acquired brain injuries. In the feedback forms, clinical professionals were asked about the perceived benefits of using Virtuality Street. A full table summarising these responses is presented in Appendix E. An excerpt from these responses is shown in Table 8.5.

In response to being asked about the potential utility of the platform, clinical professionals identified a range of uses. These broadly corresponded to the rationales for a virtual reality environment identified through this thesis, such as assessment and the practice of relevant skills for people who may have difficulties accessing the community. Some listed gradual exposure to situations as a benefit, as well as the potential to record and playback social interactions and behaviours for review.

The staff also listed a range of service users' attributes and behaviours that they felt they could learn about using Virtuality Street. Many of those listed were executive or component skills (e.g. planning, impulsivity, memory). Composite attributes were also described: for instance, how service users manage complex and conflicting situations or stimuli. Limits and boundaries were described as of importance: the point at which a service user starts to experience distress, confusion, or frustration, and the ability to handle a busy environment. The potential to learn about social interactions with members of the public was also frequently described, as was the potential to develop and practice relevant strategies.

Road safety was described by both groups of staff as a potential use of Virtuality Street, either as a component skill (waiting for a safe time to cross) or integrated into more complex route planning (exhibiting road safety practice while performing a set of tasks). We have acknowledged this as a clinical concern of community activities (see Section 5.2), but it has not been a focal concern of the design and development work reported in this thesis. During the service user demonstrations described earlier in this chapter, road safety was exercised and further described as a potential use of the environment (see Section 8.4.6).

Clinical professionals were asked whether they would engage with Virtuality Street and responded positively. All BIRT staff and seven independent hospital staff answered “Yes”. Among the remaining hospital staff, two respondees answered “possibly”, another gave the caveat of if risk was managed, and two (involved in physiotherapy and exercise) noted that it would be better suited for other fields such as occupational therapy.

Perceived risks and limitations

Understanding the barriers to clinical uptake is also of importance in the path to bringing VR into routine use. Clinical professionals were asked about the limitations that might prevent them from using Virtuality Street, what risks they could see in its use, and the extent to which they would be willing to work within the constraints of these risks. A full table summarising these responses is presented in Appendix E. An excerpt from these responses is shown in Table 8.6.

The state of Virtuality Street as a research tool was described as a limitation to its use. The characters as implemented do not fully represent the nuances of facial expression and body language, which could restrict its use for practicing and assessing social interactions. It was also noted that the environment needed to be robust and without glitches to prevent service user frustration or disengagement with the activity.

#	What limitations would prevent you from using this platform?	What risks do you see in using this platform?	Would you be prepared to take these risks to undergo assessment and therapy in a virtual environment?	Please elaborate:
BIRT6	Space - ideally the person walking would be able to move more freely.	i) Collisions in the room; ii) Motion sickness; iii) Disinhibition of aggressive responding	Yes	All potential risks could be pre-assessed and monitored
BIRT9	Ensuring the environment runs smoothly, if glitches SU more likely to become frustrated/disengage	No major depending of SU using	Yes	Probably more for therapy than assessment unless evidence that risks translate
HOSP4	Time taken to set up and program	Maybe tripping. Resulting feelings of nausea. Risk of damage to equipment	Yes	
HOSP10	Risk of anxiety or seizure	-	Yes	In **** we are used to controlled risk with patients

Table 8.6: Clinical professionals' responses on the limitations and risks of Virtuality Street (Excerpt from Appendix E)

Related to these development concerns, some issues were highlighted around the technical and practical limitations of virtual reality. The cost of equipment and limited range of other applications was a concern, as was the time involved in developing an environment, with staff concerned that they might not be able to get value from a VR device. Some were concerned about the space available in a rehabilitation centre for someone to walk around freely. It was noted that the time and expertise to set up the environment would also be a limitation. As previously discussed, demonstrations took place in rooms that would usually be used for other routine operations within a rehabilitation center, which would not be available as dedicated rooms for virtual reality activities. A follow-on to the concern of adequate space was the danger of hitting or tripping over objects in the room, which staff described as a risk that would need to be managed.

Suitability was a further concern, with worries that a virtual reality environment may be too overstimulating for some users, or could lead to them becoming distressed or agitated throughout the session. Some visuospatial and vestibular disturbances may preclude use; this was especially noted at the independent hospital, where vestibular problems were common in the type of traumatic brain injuries being treated, which could consequently increase the risk of vertigo and sickness. Feelings of nausea and

#	What would make this platform more appealing to use?	Any other comments?
BIRT6	i) Metric of safety in road crossing; ii) More avatars to interact with	A great development in the toolset available to rehabilitation providers
BIRT9	I would prefer microphone "real" response than computerised	Interested in eye tracking. Would be interested to see this platform used across a range of disciplines as can be adaptable for OT, psych + SLT
HOSP4	A good selection of pre-programmed scenarios	A very promising cognitive rehab tool
HOSP7	Is there potential for a wireless headset? An office environment	-

Table 8.7: Clinical professionals' responses on making Virtuality Street more appealing to use. (Excerpt from Appendix E)

motion sickness were described by several clinical professionals as risks to using Virtuality Street. Epilepsy and seizure risks were also described as factors that would need to be considered for use.

Some clinical professionals also described queries over the relationship between behaviours in virtual reality and those in the real world. For instance, that people may learn behaviours but be unable to translate them into real practice, which could create problems when they return to the community.

Most staff said that they would be prepared to take the given risks to carry out rehabilitation activities in a virtual environment, explaining that they would do this for people without medical conditions such as epileipsy that would produce a seizure risk. They would screen and select participants carefully and monitor them during use. As one member of the independent hospital staff explained: "In [organisation] we are used to controlled risk with patients." Those staff who responded "No" or did not give a yes/no response clarified that it would be patient dependent or would want to get appropriate clearance.

Improving appeal

Finally, staff were asked what would make a virtual reality environment more appealing for use in clinical practice. Table 8.7 shows an excerpt of the responses found in Appendix E.

Comments on improving the appeal of the system included addressing the practical limitations and risks highlighted previously, such as taking less time to set up, developing more characters to interact with, and removing the headset's cable.

Staff were also interested in additional functionality. Eye gaze tracking was suggested as a way to see where service users were looking during conversations or when carrying out tasks. It was also suggested that the system could be adapted to work with wheelchairs, where users would be able to use an appropriate wheelchair analogue to navigate the environment. They also wanted to see other environments, such as an office for vocational activities or a service user's own home.

As highlighted in the risks and limitations, staff also note that more evidence and literature would make the system appealing to use.

The clinical professionals' feedback also suggests a set of scenarios, involving re-using the Virtuality Street environment for different purposes by therapists within a clinical team. For example, social interactions for socio-cognitive work, exercise activities for physiotherapy, and road crossing and work practice for occupational therapy.

8.6 Conclusion

In this chapter we have reported on engagement activities with two groups of people involved with the rehabilitation of acquired brain injuries: service users who are recovering from a brain injury, and the clinical professionals responsible for administering care on a day-to-day basis. This work has been an important part of the user-centred approach adopted throughout this project. It has ensured that our work continues to be clinically grounded by involving the proposed end users of this technology, who may become proponents of its future use, and to develop trust and transparency in our research and design processes. It has also provided us with feedback on Virtuality Street and broader insights into where virtual reality can be furthered to progress our long-term goals towards clinical validation and adoption. The key findings of this chapter are summarised below.

Three **service users** (SU1, SU2, SU3) used Virtuality Street to attempt the VS-MET Sitting Version's set of tasks, under the supervision of a consultant neuropsychologist and the researcher. SU1 additionally attempted tasks within the regular VS-MET.

- Virtuality Street was capable of drawing out instances of **clinically relevant behaviour** that reflected each service user's deficits. SU1 had difficulties interacting with a challenging character, and his memory/insight impairment led him to think that he had been employing a socio-cognitive strategy better than he had. SU2's executive impairments showed as problems formulating plans, recovering from errors, and negative insights about her performance, while her speech and language impairments led to difficulties with reading, speech, and verbal and visual comprehension. SU3's visuospatial impairments affected her ability to navigate obstacles, and expressed negative insight when she thought her visual impairment was hindering her performance. It also enabled service users to practice taught strategies, such as for road crossing and social skills.

- We observed **what a virtual reality session might look like in practice**, following our literature-driven storyboard in Section 4.4.1. There is meaningful clinical value in a service user being briefed on a set of tasks, attempting them in virtual reality, debriefing with a review, and then putting strategies and suggestions into action. We found that Virtuality Street engaged all three service users in this procedure of carrying out tasks and discussing their perceptions and performance, with a monitor used as a visual aid to prompt discussion. The amount of clinician intervention varied between the service users, which indicates that further work must facilitate these degrees of prompting and task alteration.
- **Constraints** were identified that should be considered in the design and use of Virtuality Street and other virtual reality tools for this domain. Space is a premium in many rehabilitation centres; small rooms which serve multiple purposes may be used, creating constraints on movement and the presence of furnishings. Accents of service users and clinicians need to be considered in socio-cognitive exercises, where a prepared character may use an unfamiliar accent or phrases. We found that low-resolution images could be misinterpreted by service users as a failing in visual perception rather than a technical development factor, which needs to be considered to avoid feelings of negative insight about their performance or progress through rehabilitation.
- There is value in **testing component skills** (e.g. reading, finding something in the environment, road safety), as alternatives to more complex tasks that require putting these component skills together and managing them over time. This offers service users a way to engage with Virtuality Street if they are not ready for the VS-MET, and could also be used to gradually expose them to activities in a virtual environment to build up trust, tolerance and familiarity.
- It is critical that **in-house psychologists are involved in future work** to further the development and evaluation of Virtuality Street. Their understanding of a service user's history, nuances and behaviour is entirely necessary to interpret the observations afforded by activities in a virtual environment. Being able to use Virtuality Street with a service user over multiple sessions would greatly assist in

gathering feedback and evaluating different aspects of the environment.

Two groups of **clinical professionals** were involved in demonstrations of Virtuality Street. The first were staff from a BIRT service who had individual or group demonstration sessions over a three-day period. The second were staff at a specialist hospital for members of a UK-based organisation, working primarily with traumatic brain injuries, who attended a 1-hour group presentation and demonstration. Both groups consisted of clinical professionals from multidisciplinary teams with interest in technology to support their work, and so brought different perspectives beyond the neuropsychological angle we have taken in this thesis.

- **Conceptual models** such as the clinical model of executive functioning (Sohlberg and Mateer, 2001) are of some familiarity to clinical professionals, with some others identified. The language and concepts used by these models will be useful in developing information sheets to communicate with clinical professionals and present our work as relatable and clinically grounded.
- Clinicians see **benefits** of using Virtuality Street as a platform for rehabilitation activities, which align with the rationale for virtual reality environments set out through this thesis. Clinicians are interested in the socio-cognitive and functional behaviours that Virtuality Street can facilitate observation and review of. These could be composite sets of tasks within a larger activity, such as demonstrated through the VS-MET. They could also be executive or component skills such as planning, impulsivity, or road safety. They also see potential to develop and practice strategies through Virtuality Street in preparation for real world activities.
- Continued work with clinicians is needed to address the **limitations and risks** around Virtuality Street and virtual reality generally. There are technical and practical concerns on cost, space, time, and expertise – these will require working with clinicians to address, such as by demonstrating value and developing clear instructions for setup. Investigating a cable-less headset would mitigate concerns around comfort and safety.
- Clinicians are keen to see **improvements and additions** to Virtuality Street. It needs to be robust and needs character-based work to improve socio-cognitive interactions. Appeal could be improved through eye gaze tracking, wheelchair compatibility, or other scenarios.
- There is considerable potential for Virtuality Street as a platform to contain **multiple scenarios or activities** that have appeal across a multidisciplinary

team. For example, social interactions for speech and language work, exercise activities for physiotherapy, or vocational and safety activities for occupational therapy. This would integrate Virtuality Street and virtual reality technology into the clinical toolkit used with service users, and provide increased value for acquiring a virtual reality kit.

- Feedback from clinicians has set a **direction for clinical validation**, which falls beyond the scope of this thesis. It should consider suitability of service users for Virtuality Street and the transferability of skills to the community.
- Our demonstration sessions at both BIRT and a separate specialist hospital show overlap in the potential benefits and appeals of Virtuality Street, suggesting **generalisability** of our work beyond BIRT. Feedback from this hospital brings some different perspectives, such as a focus on risk management which had not emerged through our work with BIRT.

A limitation of these findings is that they come from a small sample size of both clinicians and service users. However, our demonstration sessions with these groups have been an essential step in the overarching goal of this clinically motivated research, which is to build towards clinical validation of Virtuality Street as a therapeutic tool. This feedback gives us confidence that the design of Virtuality Street is clinically grounded and aligns with the goals of service users and professionals working in this domain. In the next chapter we present our conclusions of this thesis and outline the next steps for our work towards this goal.

Chapter 9

Conclusion

9.1 Thesis Goals

The research described in this thesis has investigated how virtual reality can support rehabilitation activities and deliver meaningful benefits to people involved in the rehabilitation of acquired brain injuries. This thesis has reported on a collaboration with the Brain Injury Rehabilitation Trust, whose work involves the neurobehavioural rehabilitation of people with functional and socio-cognitive impairments.

For the service users of BIRT, clinical goals are concerned with the acquisition of abilities that lead to social reintegration into the community and a transfer to safe and independent living (Worthington et al., 2017). The rehabilitation of executive functioning is a key predictor of successful reintegration (Sohlberg and Mateer, 2001), but there are barriers. Access to community settings is not always possible, and clinicians seek assurances that service users can engage in the community safely, appropriately and independently. Rehabilitation activities such as the Multiple Errands Test (Shallice and Burgess, 1991) exemplify the gold standard of rehabilitation: to put someone in a real environment with tasks to complete, to facilitate the observation of socio-cognitive and functional behaviours, strategies and emergent deficits. However, there are practical difficulties: such activities are irregular and costly, unpredictable and uncontrollable, and difficult to record.

Virtual reality simulates real world scenarios that are difficult to re-create in the real world due to cost, time or safety (Rizzo and Koenig, 2017). It uses realistic, immersive and interactive experiences to psychologically engage users, such as to address disorders or phobias, and to control gradual exposure to situations that they may aspire to experience in the real world (Botella et al., 2017; Kothgassner et al., 2019; Emmelkamp et al., 2020). As such, virtual reality aligns with the goals of neurobehavioural rehabilitation activities designed for community reintegration:

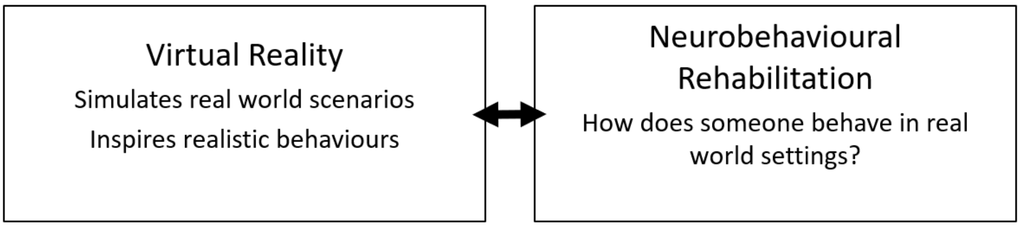


Figure 9-1:
The relationship between virtual reality and neurobehavioural disability underpinning our research.

This thesis has laid out the iterative approach of literature study, in situ observations of clinical practice, and input from clinicians to explore the types of activities that have meaningful benefit to clinicians and service users at BIRT. It has set out to achieve five goals:

1. To explore the types of assessments conducted in clinical practice for the rehabilitation of executive dysfunction, including their purpose, strengths and limitations.

In Chapter 2 we established the domain within which we are working, presenting the functional and socio-cognitive challenges attributed to executive dysfunction and neurobehavioural disability. Chapter 3 described the theoretical goals of the neurobehavioural rehabilitation model and reported on site visits to understand how the structure of rehabilitation services supports acquisition of community skills, and the practical challenges in accessing the community. In Chapter 5 we explored the purpose and benefits of behavioural assessments, and their application within a rehabilitation centre (BADS; Wilson et al., 1996) and in the community (MET; Shallice and Burgess, 1991). This developed an understanding of the strengths and limitations of these assessments, and identified the salient features of these assessments that contribute to clinical goals.

2. To iteratively design and develop a virtual reality environment prototype that we expect to have meaningful use in a therapeutic programme by echoing aspects of clinical assessments.

In Chapter 4 we presented the Virtual Bus Stop for prototyping interactions between clinicians and service users, framed within the context of buying a bus ticket. This was clinically grounded in roleplaying exercises conducted in rehabilitation centres. Clinician feedback was used to identify desirable features and technical constraints, and to develop the shared expectations of a virtual reality tool. Using lessons from the Virtual Bus Stop and building upon our evolving understanding of assessments, we designed and developed Virtuality Street in Chapter 6. Virtuality Street is designed to enable functional, community-based assessments to be carried out in a safe virtual reality environment that is a recognisable analogue to real world settings. We developed the Virtuality Street Multiple Errands Test (VS-MET) to demonstrate how clinical assessments could be integrated into Virtuality Street, and adapted it to the VS-MET Sitting Version in response to clinician input.

3. To determine the efficacy of a virtual reality environment to observe behaviours associated with executive functions in both neurotypical people and those with acquired brain injuries.

In Chapter 7 we reported a lab-based study involving neurotypical participants using Virtuality Street to attempt the VS-MET. We found that participants exhibited behaviours and encountered challenges to their functional completion of tasks and social interactions that bear relevance to clinical interests. These participants spoke of five broad themes on their interaction with characters, movement in the environment, time-keeping, comparisons to the real world, and strategies to functional tasks. In Chapter 8, three service users at a BIRT service attempted the VS-MET Sitting Version, where we observed executive behaviours that reflected their individual strengths and deficits.

4. To gather feedback on the utility and validity of a virtual reality environment from clinical professionals.

Throughout this research we have employed a user-centred approach to gather feedback from clinicians to ensure the grounding of our work. In Chapter 8 this culminated in demonstration sessions with clinical professionals from BIRT and a specialist hospital for members of a UK-based organisation. We gathered feedback on the utility, potential, limitations and risks of Virtuality Street as a demonstrator system for virtual reality assessments. This feedback complements our understanding of clinical interests and sets future direction for this research.

5. To present design guidelines for the future development of virtual reality environments for acquired brain injuries and broader therapeutic applications.

Through our analysis of neurobehavioural activities we have produced design guidelines and demonstrated their use through the development of Virtuality Street. In this chapter we will present them as a contribution.

This chapter concludes the thesis by presenting the key contributions made by this research and its future direction.

9.2 Contributions

Contribution 1: Analysis of assessments to establish design guidelines for virtual reality environments to support community-based activities

A core contribution of this thesis is a HCI-driven analysis of behavioural assessments used in the rehabilitation of executive dysfunction. This analysis is presented to inform the design work of HCI researchers looking to understand and support rehabilitation activities.

As HCI practitioners, we are interested in the interactions that take place between people in different domains, understanding what makes a good interaction between them, and how technology can be used to meaningfully support those interactions. This involves looking at the goals and challenges of any given interaction. In this research, that domain is rehabilitation of executively impaired functional and socio-cognitive abilities, and the interactions taking place between service users and clinicians whose goal is to prepare people for community reintegration. Throughout this research we have immersed ourselves within this domain, working with professionals involved in the day-to-day provision of care and community rehabilitation, to understand the activities and interactions contained within. By doing so we have backed up knowledge of theory with an understanding of application to practice.

Our analysis of centre-based assessments, focusing on the Behavioural Assessment of the Dysexecutive Syndrome (BADS; Wilson et al., 1996) have resulted in a set of implications for research in this area. These were community-related functional behaviours of clinical significance to be observed (Table 9.1), the types of data to be collected that are of importance to clinicians looking to interpret behaviour (Table 9.2), and an initial set of design considerations for designers interested in supporting observations and data collection (see Section 5.4.4).

Building upon this, we performed an ethnographically inspired observation of a community-based assessment, the Multiple Errands Test (MET; Shallice and Burgess, 1991), being conducted with a service user. This enabled us to realise the practical constraints and realities of performing activities in real community settings. In Section 5.6.4 we

Functional Behaviours of Clinical Significance
1. Inhibiting existing behaviours and triggering novel behaviours.
2. Planning out an efficient route to meet an objective.
3. Planning a journey around a series of constraints.
4. Perform interdependent steps to complete an activity.
5. Estimating and managing time.
6. Multi-tasking between tasks.
7. Exercising insight and self-awareness.

Table 9.1: Functional behaviours identified as having clinical significance for community reintegration.

Functional Data of Clinical Significance
1. Number of errors made in tasks.
2. Time spent completing tasks/sub-tasks.
3. Time spent planning tasks.
4. Properties of routes taken.
5. Accuracy of temporal estimation.
6. Reliance on prompting.
7. Levels of insight through self-reporting and discussion.

Table 9.2: Functional data identified as having clinical significance for the observation and interpretation of community relevant behaviour.

analysed how observations of our derived set of functional behaviours are facilitated by community assessments, and how data of clinical interest is collected in the real world. We also analysed how observations of socio-cognitive behaviours were facilitated by a diverse and flexible environment. The opportunity to ask for help (even when prohibited) demonstrated inhibition impairments and employment of strategies. The variety of people in the environment (a mix of men and women, customers and shop assistants) allowed observations of social behaviours such as bias and compliance to convention. We derived a list of practical limitations to conducting community assessments that were driven by the goals of clinicians and the challenges impeding those goals. Finally, we used these limitations and factors of socio-cognitive behaviours to expand our list of design guidelines, which we present in Table 9.3.

Our analyses have resulted in this set of design guidelines derived from the goals of clinical assessments and administering clinicians, and the limitations of conducting such assessments in a rehabilitation centre and the community. We have also produced a set of behaviours and data that have clinical significance. We have gone on to

Design Guidelines for a Virtual Reality Environment to Support Community-based Assessments
1. A virtual reality environment should support assessments of individuals going about real everyday activities in the community.
2. It should support assessments involving regulation of multiple tasks, pieces of information and rules with competing demands and priorities, managed over time.
3. It should enable the practice of both functional and socio-cognitive everyday life skills.
4. There should be distractions, temptations and frustrations to 1) challenge an individual's compulsions and inhibitions and 2) challenge them in both a functional and socio-cognitive context.
5. It should enable people to practice learned strategies in real world settings independently of the prompting or offloading techniques facilitated by a clinician.
6. Social interactions should be afforded with people with different personalities and temperaments.
7. There should be recording of data relevant to socio-cognitive and functional behaviours to support assessment and interpretation, and facilitate insight. Recordings should support the clinician's continued role to interpret this data for clinical decision making.
8. Clinicians should be given control over challenges to gradually expose people to situations of a desired difficulty, such as with social interactions.
9. The environment and its assessments should be deployable in the rehabilitation centre without the overheads of removing a service user from the centre, and providing a quick escape for service users experiencing distress or agitation.

Table 9.3: Design guidelines for a virtual reality environment to support community-based assessments.

develop Virtuality Street to demonstrate how these guidelines could be incorporated into an environment that supports clinically grounded interactions, observation of these behaviours and collection of data.

Contribution 2: Development of Virtuality Street as an experimental platform to create rehabilitation activities

Using our design principles, we have contributed the development of Virtuality Street. Virtuality Street is an experimental platform to articulate general design ideas and to understand the grounding of our work in clinical practice through user-centred design iterations. From a HCI perspective, user-engaged design iterations are absolutely necessary to assure and improve the validity of a design in terms of human needs and aspirations. It is thus a vehicle for driving user-centred iterative design that seeks to develop a deeper understanding of the practical meaning of design ideas through further engagement with people involved in rehabilitation.

To date, we have developed Virtuality Street as a virtual community as a recognisable analogue of real world settings in which neurobehavioural rehabilitation activities can be created that echo aspects of recognised clinical assessments. Through our design iterations we have demonstrated its utility by creating assessments, the VS-MET and VS-MET Sitting Version, that make use of it as an environment to deliver tasks and challenges. Our feedback sessions with clinical professionals have identified the clear potential and need for further activities to be designed that make use of this environment's capacity to deliver safe and controllable exercises, such as for route planning, social interactions or road safety.

We have further demonstrated that Virtuality Street can support assessments that are capable of delivering challenges to executive functioning. Additionally, it can facilitate objective observations of behaviour, discussions for reflection and strategising, and recording of data that may assist in clinical reporting.

In our lab-based study with neurotypical participants, we found that none were able to complete the VS-MET without errors. Since there were no discernible patterns to task performance, we suggest that people were able to devise different strategies to approach tasks and overcome challenges. Participants were able to use recordings of their performance to rationalise their behaviours and expose strategies. They talked about five broad themes on their interaction with characters, movement in the environment, timekeeping, comparisons to the real world, and strategies to functional tasks, which collectively add to our evolving understanding of how people behave in such environments.

In our demonstrations with three service users, we found that Virtuality Street was capable of drawing out instances of clinically relevant behaviour that reflected each service user's deficits. It also enabled service users to practice taught strategies, such as for road crossing and social skills.

Contribution 3: Guidelines for a structure to support interactions through virtual reality

Our final contribution is an understanding of how virtual reality environments can support four types of interaction that are critical to rehabilitation goals: *challenging*, *prompting*, *discussing*, and *reporting*.

Our demonstration sessions with service users gave us our first opportunity to view how a virtual reality environment could be used in practice by a clinician and service user. In Chapter 4 we presented a storyboard that envisioned how a virtual reality rehabilitation session might take place, in which a service user attempted a task unaided, reviewed their performance and experiences with a clinician, and then attempted the task again armed with new insight and strategies (see Section 4.4.1). In our lab-based study in Chapter 7, the conducting researcher took a similar hands-off approach to let participants conduct the VS-MET unprompted, and then discussed their behaviour and performance using a playback – a recording of the session from the participant's view in the head-mounted display. From our observation of assessments in Chapter 5, we also learned how briefing and debriefings were used to set appropriate context for activities.

In the demonstration sessions reported in Chapter 8, three service users attempted a set of tasks in Virtuality Street using a structure informed by this earlier work.

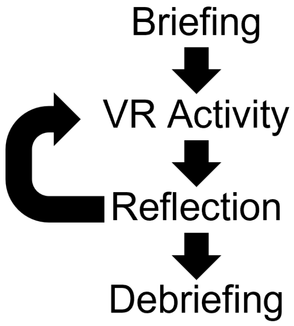


Figure 9-2:
The structure of a virtual reality session for rehabilitation.

This structure envisions how virtual reality sessions can be run in practice: (1) a service user is briefed on the activity, (2) they attempt a task(s) set by the clinician, who intervenes and prompts as needed, (3) they reflect upon their experience with a clinician in a dialogue, facilitated by a playback/display of the environment, (4) they debrief to discuss the session and consider how it has supported the service user's goals. The reflection in (3) may lead to the development of strategies or other insights that would benefit from immediate exposure to the environment, and so could be followed by re-entering the virtual environment.

The virtual reality activity supports two types of interaction: *challenging* and *prompting*.

Challenging: In our work so far, the functional challenges delivered in virtual reality have been largely pre-defined (VS-MET). In future work we discuss how we can enable clinicians to have greater control of the challenges delivered to service users. Socio-cognitive challenges have been more involved and facilitated clinician control of characters. We have demonstrated different interactive paradigms on a continuum of control that enable the delivery of socio-cognitive challenges. Giving clinicians the ability to drive conversation through a microphone gives great flexibility in varying discourse, but pre-programmed responses are also capable of engaging users and drawing out clinically relevant interactions. We argue that there may be a range of appropriate interactive paradigms to use when challenging service users. There is value in deviating from a set script and triggering executive thinking, and clinicians want to vary responses and challenge users. However, as observed with "Service User 1" in Chapter 8, standardised and similar responses can be useful for practice.

Prompting: During the BADS and MET, we observed prompting to be used; in fact, it was recorded as clinically significant data. In demonstrations with service users, we found that Virtuality Street enabled varying degrees of prompting to be used, with significant interventions (sitting alongside and guiding through every step) for the most impaired service user, occasional prompts for the median service user, and a complete absence of prompts for the least impaired.

The post-virtual reality discussion supports the critical interaction of *reflection.* The value in playing back a user's attempt at tasks was shown in Chapter 7, where it facilitated detailed reasoning about each participant's approach to the tasks and their beliefs about the environment. In our service user demonstrations, Virtuality Street again supported reflection on performance; this did not use a playback but we did find value in looking around the environment on a monitor during discussion to reflect upon task completion and to correct insight.

Our proposed structure of a virtual reality session allows for reflection to lead to re-attempting a virtual reality activity. From our observations, we found that the steps of reflection and re-attempting may not take place sequentially. For 'Service User 1', the only service user who put on the headset for a second attempt, there were discrete steps involved in discussing behaviours and strategies, and then re-entering Virtuality Street to put them into practice. For 'Service User 2', these steps were integrated into a single experience in virtual reality, where she and the consultant discussed behaviours and strategies during the tasks to immediately put into practice.

The fourth interaction, *reporting*, is crucial in the debriefing and tracking of a service user's rehabilitation. We have demonstrated some early work in using objective data to assist in reporting, that can be used to share information about progress with other members of a clinical team or to demonstrate progress to a service user.

This general structure of a virtual reality session and affordances of the environment support these four key interactions in rehabilitative work. We present this core structure and the virtually mediated interactions within as a foundation for work in this area, such that clinical professionals can define a protocol for virtual reality sessions in clinical practice. It helps clinicians to envision how such sessions may fit into other structured activities for neurobehavioural rehabilitation, and demonstrates the essential inclusion of a clinician to exercise these interactions.

9.3 Future Work

Next steps with BIRT

Our relationship with the Brain Injury Rehabilitation Trust has underpinned the research reported in this thesis. The ultimate goal for this clinically motivated research is the validation of a therapeutic process or intervention, through an evaluation of the impact on clinical outcomes. Through our work with BIRT we have immersed ourselves in the clinical domain to ensure that we are designing and developing tools that are grounded in rehabilitation and reflect the realities of practice. Yet this research has been rightly and necessarily constrained by the nature of the domain and individuals we are working with. Although we met and learned about many service users in BIRT, it was essential that we exercise caution when asking them to use a technological tool. Our engagement activities, in which we exchanged knowledge with clinicians and established a strong working relationship, was vital not just because they are the experts working in this domain, but they are the expected end users of this technology. Furthermore they are gatekeepers to service users who must have confidence in our work. Our methodology throughout this research has been to develop trust and transparency, and to ensure that clinicians retain authority and ownership of the rehabilitation process and the methods and tools that they use.

Within the scope of this thesis, we have run short (15-30 minutes) demonstrations with three service users and gathered important information about how they interact with Virtuality Street. We have also gathered feedback from clinical professionals who see value in this research. Although this thesis has concluded, our research very much has a future with further engagement with these two groups.

In July 2021 we visited BIRT's Research Fellow, Dr Sara da Silva Ramos, who has guided this work from its inception. The next step for our work with BIRT is to begin using Virtuality Street with service users on a frequent basis, in order to inform further development work and prepare for evaluation of clinical outcomes. Such work has requisites. As we concluded in Chapter 8, further work must involve an in-house psychologist who has an integrative understanding of a service user's state and goals, who can make interpretations of observed behaviour, and who can report on its use. Virtuality Street must then be developed to a point where it can be reliably used by a clinician. To this end, it will be essential for a computer scientist or technologist to be positioned with BIRT to work with the psychologist, with responsibility for setting up and maintaining Virtuality Street, or performing additional work on it.

A key concern raised by clinical professionals in Chapter 8 was the transferability of skills to real world settings. We propose this to be an area of investigation for a psychologist, who could identify service users capable of performing real world community assessments as a baseline for comparison.

Another concern raised was on cybersickness. Rebenitsch and Owen (2021) propose guidelines, such as habituation, session frequency and length, as strategies to mitigate cybersickness. These will have implications for a psychologist and technologist to consider when planning sessions. We propose that their work should include gathering demographics to better understand the issue of cybersickness susceptibility amongst this clinical population.

Development of Virtuality Street

Future work with the Brain Injury Rehabilitation Trust necessitates further development of Virtuality Street. Chiefly the robustness and usability of Virtuality Street must be developed to a point where it can be reliably set up and used by a clinician. This must include a guided process to set up a virtual reality session, and appropriate handling of or clear route to recovery from any crashes or errors, such as loss of tracking. Such robustness is key not to just the reliable use of the software, but to building confidence in Virtuality Street as a tool to be routinely used in practice. Clinical professionals also expressed concern that glitches could lead to service user frustration or disengagement.

Some suggested areas of development for Virtuality Street are outlined below.

Clinician user interface

In the Virtual Bus Stop prototype shown in Chapter 4, we presented a clinician user interface that could be used to deliver utterances and control the facial expressions of a character. Such an interface is essential for the operation of Virtuality Street by a clinician, who will require controls to set up sessions, control interactions with different characters, vary challenges such as traffic or noise, and record or view data. The clinician user interface is also key to controlling some of the other areas of development listed in this section.

Scenarios and difficulty

Feedback from clinical professionals has pointed to the development of multiple scenarios and assessments that could be delivered within Virtuality Street. Future development should support the configuration and storage of such scenarios so that they can be selected and deployed. We envision a toggle of different aspects of the environment, such as specific shops or posters, that clinicians could choose from when designing a scenario and assessment. Difficulties of activities could make use of these options. For example, a simple Multiple Errands-style activity may involve two shops located on a single street, surrounded by residential buildings; a more challenging version could involve a user visiting a number of shops located around the environment, where the residential buildings have been replaced by commercial ones.

Further to this idea of difficulty, stimuli and obstacles should be included as toggleable and scalable. This could include the amount and type of ambient noise in the environment, such as fire alarms or roadworks, or how much traffic or pedestrian activity a user has to contend with whilst going about their tasks.

Social interactions

Feedback noted that the characters as implemented do not fully represent the nuances of facial expression and body language, which could restrict its use for practicing and assessing social interactions. Further work is needed to record more believable facial expressions and expand the bank of body movements that can be drawn upon. Giving clinicians control over these behaviours is also essential. We suggest that “personalities” could be created for different characters so that clinicians can select the type of person they would like to see service users interact with.

Having characters moving around Virtuality Street, and allowing clinician control of/service user interaction with any of them, could greatly improve the potential to explore how people interact with the world around them. Our observations of “Adam” in Chapter 5 come to mind, where interesting behaviours were observed as he approached strangers to ask for help, expressing preferences (only initiating conversations with women) and breaching social conventions (asking a customer for help instead of a shop assistant).

Locomotion

Virtuality Street was implemented with a locomotion technique by which users hold down a button to move in the direction they are looking. The primary reason for implementing this technique was so that travel time was a non-negligible factor in traversing the environment; it takes time to move between two points, rather than reducing this to a non-factor through a technique such as teleporting. Participants in Chapter 7 talked about speed as a limiting factor in their exploration of the environment and usability, with one participant experiencing physical discomfort. There should be further work with clinicians and service users to use a locomotion technique (or choice between multiple) that are comfortable and intuitive to use and retain transferability to real world settings. Some participants in various demonstrations have even enquired about a “wheelchair-mode”, where users could drive movement by turning the wheels of a wheelchair.

Recording and playback

The use of recordings was demonstrated in Chapter 7, where participants watched their session back to facilitate reflection on their behaviour and strategy. There is value in such recordings and playback to foster insight, where service users can have an objective view of their behaviour, which may be clouded by diminished self-awareness. Even without this recording, we witnessed such value with service users and a consultant who could view the environment on a monitor. Playing back the entire session may not be necessary; a clinician could “bookmark” a particular point in a session for review.

There may also be value in playing back a session from a different perspective (Lindner et al., 2021). This further facilitates an objective view of behaviour, where a service user could see how they behave from another person’s viewpoint.

Graphs and reporting

Following on from the area of recording and playback, data about a virtual reality session can be used to assist in the reporting of activities. Reporting can involve the recording of objective data (routes, commentary, number of errors; see Table 9.2). As discussed in Chapter 5, it is a time overhead and subject to difficulties in gathering data (recording conversations in the community, witnessing behaviours from afar, maintaining attention between running an assessment and making notes). In Section 7.6 we presented some early work to assist in this reporting, through the generation of images that display paths taken through an environment. The automated generation of such graphs, such as showing properties of routes, time spent in different locations,

Figure 9-3:
Demonstration at an education college for people with disabilities.

frequency and duration of pauses, could assist in the collection and reporting of clinically relevant behaviours. Integrating reporting tools into Virtuality Street has the potential to further support the work of clinicians.

Application to other types of rehabilitation

The focus of our work has been on rehabilitation of functional and socio-cognitive skills as a consequence of executive dysfunction and neurobehavioural disability. Whilst this work has taken place primarily with BIRT, we have conducted demonstrations with other groups during this research. Staff at a specialist hospital for members of a UK-based organisation provided feedback on Virtuality Street in Chapter 8. Outside the scope of this thesis, we have also demonstrated to an education college for people with disabilities (Figure 9-3). Through conferences and public engagement events, we have attracted interest from a variety of rehabilitation professionals and people with disabilities. The potential value to practicing functional and socio-cognitive skills are not solely limited to executive dysfunction, and may have benefits for people with autism or social anxieties, or who are bed-bound due to disability. In the Covid-19 pandemic, social anxiety in the community has been exacerbated by changing social norms around masks or distancing (Saint and Moscovitch, 2021), which could benefit from controlled exposure to community settings in virtual reality.

Advances in HMD technology

The presence of a cable trailing from a head-mounted display was frequently commented on by our neurotypical participants, service users and clinical professionals during virtual reality sessions. Often a researcher would need to hold or move the cable to prevent a user from getting tangled or tripping over, such as in Figure 9-3. Although mobile VR has existed for several years, high-end virtual reality powered by a dedicated computer has relied upon such cables in order to run. As advances in head-mounted displays continue, it is now possible to get wireless adapters that remove the need for a cable, such as the Vive Wireless Adapter[1]. The quality of mobile headsets has also improved and can support wireless streaming to a desktop – this is essential for our work where a therapist needs to view what a service user is looking at.

The increase of wireless headsets that are not reliant on external trackers open up possibilities for interaction. In a sufficiently sized space, exercises could be designed that do not require a locomotion technique beyond walking. This could include crossing a road, which was a scenario of significant interest to clinical professionals.

Another advancement in head-mounted displays is the integration of eye tracking. Whereas it can usually be difficult to determine what someone in virtual reality is looking at, headsets with eye tracking allow for an understanding of how someone is viewing the virtual world around them. This can be helpful for understanding how someone scans to search for objects or information, or how often they look at particular stimuli. It also has the potential to enhance interactions, such as by having characters respond to eye movement if it is inappropriate (Vidal et al., 2015).

Information packs

Our demonstrations with clinical professionals have generally been prefaced with presentations describing the context and purpose of our work. As we move towards the goal of using Virtuality Street in clinical practice, we should seek to develop information packs for dissemination of our research to clinicians. In Chapter 8 we sought feedback from clinical professionals about their knowledge of models for rehabilitation, such as the clinical model of executive functioning (Sohlberg and Mateer, 2001). This feeds into the language to be used in such packs to contextualise information in familiar terms and to demonstrate grounding in practice.

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[1] https://www.vive.com/uk/accessory/wireless-adapter/ [accessed 03-08-2021]

9.4 Thesis Conclusion

For people involved in the practice and assessment of skills in the community, virtual reality offers the exciting potential to draw out behaviours that would not normally be achievable in a controlled risk environment or to be observed in detail. It allows for functional and socio-cognitive behaviours associated with executive dysfunction to emerge through interactions with an ecologically valid and clinician-driven virtual world, that can facilitate meaningful interactions between users of brain injury services and clinicians.

Through this thesis we have analysed the current state of rehabilitation activities for people whose goal is functional and social reintegration to the community. Through analysis of the literature and in situ observations we have established an understanding of clinical activities and framed these in a Human Computer Interaction perspective to establish clinically grounded frameworks to support virtually mediated clinician–service user interactions. Our experimental platform, Virtuality Street, has been constructed to demonstrate how such interactions can be afforded through these design guidelines, and is capable of exposing key behavioural correlates of executive dysfunction.

The research reported in this thesis has fostered a successful collaborative relationship between Human Computer Interaction researchers and clinical professionals at the Brain Injury Rehabilitation Trust. It has enabled the mutual exploration and evolving understanding of how virtual reality can deliver meaningful benefits to people involved with the rehabilitation of acquired brain injuries. This relationship paves the way for further work evaluating how interactions through Virtuality Street can be designed to support routine use and impact clinical outcomes.

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Appendix A

December 2015 Transfer Report – Ethical Considerations section

7.5 Ethical Considerations

The studies being undertaken at Chalkdown House and Graham Anderson House must be treated as sensitive in nature. Ethical issues arising from collection of data regarding health are compounded by the executive dysfunction that make subjects of observation interesting to us. The difficulties with reasoning and decision making that are inherent with executive dysfunction raise questions as to the ability of a service user to provide permission to participate in a study. For instance, both locations can house service users detained under the Mental Health Act (1983), so may involve people for whom decisions are made by hospital staff.

In all matters pertaining to ethics in our research, we ultimately defer to the guidance of our clinical team from the Brain Injury Rehabilitation Trust. As professionals working in this field with intimate familiarity of the challenges in working with this vulnerable group, they are best placed to advise on the ethical considerations that arise. In the case of studies at BIRT facilities, there will be strict criteria that must be met in the planning, conducting and reporting of research. We have a commitment as ethical researchers to actively seek definition of these requirements and establish a plan with the involvement of gatekeepers.

It is therefore essential that no form of data is collected without seeking permission from the appropriate consultant and the persons responsible for the decision making of observed service users. In the pursuit of this permission we must consider what data might be collected and why different recording techniques are appropriate and necessary. Our seeking of video recording in the first study comes from the objective to analyse non-verbal behaviour, but video would be inappropriate for the recording of dialogue only. The detailing of how data collection will be analysed and used shall be a part of any petition for permission. We must expect that this permission could be withheld for a given technique of data collection, in which case we should review alternative methods of observation.

It may be possible that voice and in particular video recordings are required to stay at the hospital to avoid exposure to the public domain. In this case data analysis would need to be carried out at the hospital in question and arrangements would need to be made for this to happen. If permitted off-site, we propose that raw study data is stored on a secure server at Designability and be only accessed there. Any portable storage devices used for the recording and transfer of data must be wiped after use.

The protection of service users must be paramount in our studies, and if service users are exposed to a virtual therapy environment in a future study we will need to consider contraindications to ensure a safe experiment. This protection extends to confidential treatment though, and shall be maintained in any observations taking place. All references and recordings should be anonymous and contain no data that could make someone personally identifiable. One point that remains to be determined is the need to see a service user's face in a video recording; this is to be discussed and if deemed unnecessary could result in a camera being placed behind them.

By taking steps to protect service users' anonymity and confidentiality, collecting and storing data in an appropriate way, and by involving clinical consultants in establishing clear guidelines, we believe that we will develop ethical working practices for studies involving brain injury service users.

There is also potential risk for the researcher on-site due to the behaviour that may be exhibited by service users, who are in some cases detained under the Mental Health Act. This means that they are considered a risk to themselves or others. Consequently, the researcher shall seek appropriate guidance prior to going to the BIRT sites, and be inducted with safe working practices upon arrival. The researcher shall also be accompanied by a staff member when interacting with service users, and shall adhere to any guidelines laid out.

Appendix B

Disabilities Trust Research Ethics Committee Application Form

The Disabilities Trust

- Research Ethics Committee (REC) Application -

Name of lead applicant Zack Lyons / Dr Sara da Silva Ramos

Highest qualification achieved ☐ NVQ ☐ BSc ☐ MSc ☐ Doctorate ☐ Other

If OTHER, please specify ___________________________

Are you a member of staff? ☐ YES ☐ NO

If YES, please state Division and job title _______________

Is your study part of a degree? ☐ YES ☐ NO

If YES, please specify ______________________________

Title of project Virtual Therapy: An Interactive Story-Driven Environment for the Rehabilitation of Acquired Brain Injuries

Aims The project is a collaboration between computer scientists and designers of assistive technology to address the effects of executive dysfunction: a cluster of impairments that affect behavioural regulation and task completion. It has three aims:

- To develop a virtual environment for the assessment and rehabilitation of executive dysfunction.
- To involve clinical practitioners in the design and usability evaluation of the virtual environment as a therapeutic tool.
- To identify the most salient features of the virtual environment for addressing therapeutic goals in a clinical rehabilitative setting.

The goal of this stage of the project is to facilitate end-user involvement with clinical practitioners and service users. Feedback will be gathered from these groups on the methodology, the appeal and usability of the system, and the provision of information for relevant parties.

Method The virtual reality demonstration will be set up in a room within a rehabilitation centre, and clinical practitioners will be invited to attend at any time during the day. Staff will be encouraged to bring service users at their discretion.

Each virtual reality demonstration shall consist of:

Participants: 1x Project Research Engineer, 1x Clinical Practitioner or 1x Service User

Time: 5 minutes – briefing with participant

15 minutes – participant uses the virtual environment

10 minutes – participant will be asked to provide feedback through a questionnaire and verbal questions

Total time: 30 minutes

Procedure:

- The virtual environment is accessible through a head-mounted virtual reality display, consisting of a headset worn over the eyes and headphones. Users will see a virtual high street containing shops, traffic and virtual characters. They will be asked to find pieces of information, which can be found either by looking around the environment or by talking to virtual characters. The characters are controlled by the researcher through a mouse and keyboard.

- Any member of staff or service user can participate and provide feedback. Involvement will need to be discussed with the research engineer if a participant is pregnant, under the influence of alcohol or drugs, is sensitive to light, or is experiencing acute illness.
- When arriving on-site, the research engineer will set up the virtual environment. The research engineer will then be available throughout the day to meet practitioners, introduce them to the virtual environment, and answer any questions. Participants will take it in turns to use the virtual environment by putting on the head-mounted display, or can observe the system in use by someone else if preferred.
- Participants will be briefed before putting on the head-mounted display and attempting to find information in the environment. The virtual characters will be controlled by a researcher. When the participant has finished, asks to stop, or when fifteen minutes have elapsed (whichever comes first), they will be asked to provide feedback on the demonstration.
- The researcher will request consent from all involved to record head movement with the head-mounted display, audio through a microphone, and feedback given by the service user and clinical practitioners. All data will be anonymised and stored securely on protected computers.
- One room is required with a table, chairs and power socket for the duration of the session. No further materials are required.

Innovation Existing clinical techniques for the practice of routine behaviours and social skills in real world settings require service users to leave their rehabilitation centre. Such techniques cost time and money, and may be inappropriate for those who are confined to the centre for safety or who are bedbound.

Assessments in a virtual environment have the benefit of enabling the manipulation, and therefore understanding and evidencing, of external factors on performance (e.g. distractors, time constraints, fatigue – for example, by cross-referencing with sleep data). It further allows for the assessment of behaviours in novel situations which may be difficult to recreate in the real world (e.g. what do I do if the shop does not have the ingredient I need for my cake? What if my bus is delayed? Who do I talk to if I'm lost? Such situations can be recreated in a virtual environment). Virtual environments also offer safety and quick intervention (e.g. being next to virtual traffic rather than real traffic, being able

	to leave the environment immediately if becoming distressed). Due to these benefits, the use of virtual reality environments to deliver assessments in real world scenarios is increasing in other rehabilitation domains, such as physical therapy or PTSD. The assessment and training of social skills and routine behaviours in a realistic virtual environment is novel, and our research to date has focused on establishing baseline performance data for the healthy population.
Expected benefits	The use of virtual environments has the potential to reduce the time and financial costs involved with running an assessment of this nature. Assessments and training can be repeated multiple times in a secure space within a rehabilitation centre, without the time involved in travelling to external sites and risk to service users or the public. Activities in a virtual environment can be digitally recorded, allowing clinical professionals to analyse behaviour that would be difficult to record in a public space. Through these sessions we expect to: - Develop information sheets for communicating with clinical practitioners and service users. - Seek service users' feedback on how technology can be used to improve engagement in therapy. - Investigate the feasibility of our research including the burden placed on participants and the levels of distress that service users might be exposed to. - Explore further findings and research topics that are relevant to this project. - Identify outcome measures which are meaningful and relevant to service users.
Estimated costs	[Please use the Research_Budget.xlsx sheet to calculate the estimated costs to DT of the project. This information is gathered for audit purposes only, unless otherwise agreed between the relevant parties.]
Start date	24/08/2017
Completion date	[Insert planned completion date]
Is your study research[1]?	☐ YES ☐ NO
Do you need IRAS approval[2]?	☐ YES ☐ NO

Date of submission	**Signed**

For office use only

Approved by divisional Director? ☐ YES ☐ NO ☐ N/A

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[1] To determine whether your study is research, please use the Health Research Authority online tool available here: http://www.hra-decisiontools.org.uk/research/redirect.html and attach a copy of the outcome to this application.

[2] To determine whether your study needs to be approved by a body within the Integrated Research Application System (IRAS), such as the NHS Research Ethics Committee, please use the Health Research Authority online tool available here: http://www.hra-decisiontools.org.uk/ethics/ and attach a copy of the outcome to this application.

Appendix C

Participant Information Sheet

N.

PARTICIPANT INFORMATION SHEET

WHAT WILL HAPPEN

You will be asked to attempt a number of tasks in a virtual environment. You will first be asked to provide some information about yourself and given this sheet to read through. You will then put on a virtual reality headset and given a short warm-up to get used to looking and moving around the environment, followed by a break if needed. When you are ready you will put back on the virtual reality headset and be given a set of tasks to attempt. When you are done you will be asked to talk through your experience. Your participation is voluntary and you may stop at any time. A researcher will be with you throughout the experiment to answer any questions you may have.

TIME COMMITMENT

The study typically takes around 30-40 minutes.

PARTICIPANTS' RIGHTS

You have the right to withdraw at any time without prejudice and without giving a reason.
You have the right to omit or refuse to answer or respond to any question that is asked of you.
You have the right to have your questions about the procedures answered. If you have any questions as a result of reading this information sheet, you should ask the researcher before the study begins.

BENEFITS AND RISKS

Some people experience “virtual reality sickness”, which may involve nausea, dizziness or discomfort. You should ask to stop immediately if you feel uncomfortable during the study. Please inform the researcher now if you:

- Have a pre-existing heart condition
- Are unable to safely perform physical activities
- Have a formally diagnosed psychiatric condition such as anxiety or PTSD
- Are pregnant
- Are aged over 65
- Are currently experiencing sickness, fatigue or general illness
- Are under the influence of alcohol or drugs

Your participation in this study is voluntary.

CONFIDENTIALITY/ANONYMITY

The session will (if you consent) be audio and video recorded, along with data about your activity in the virtual world. The collected data will be stored securely and access will be restricted to members of the project. The video and audio will not be distorted because it would interfere with the study and decrease the research potential of data. However, the recordings will not include personal information, such as your name. The data will be connected exclusively with a number.

DATA RETENTION AND PUBLICATION

The data will be securely archived and retained after this study finishes for further research. Other researchers might be granted access to this preserved data for further research, providing that they agree to preserve confidentiality. Subject to your consent, data extracted from the study may be used during presentation at conferences or published within academic papers. You can still participate in the study and consent for your

N.
data to be analysed even if you choose not to consent for your visual and audio data to be presented or published.

FOR FURTHER INFORMATION
I will be happy to answer your questions about this study at any time. Contact details of the principal researchers are below. If you would like to be informed about any findings that result from this study, you can choose to provide your email address. The address will be used exclusively to inform you of the results of this study.

Researcher:

Mr Zack Lyons
Centre for Digital Entertainment
Department of Computer Science
University of Bath
z.lyons@bath.ac.u[redacted]
[redacted]

Supervisor:

Dr Leon Watts
Department of Computer Science
University of Bath
l.watts@bath.ac.uk

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INFORMED CONSENT FORM

Please tick if you agree:

Consent to Participate

☐ I have read and understood the Participant Information Sheet.

☐ Questions about my participation in this study have been answered satisfactorily.

☐ I am taking part in this study voluntarily. I understand that taking part in the project will include being interviewed and that the collected data will be analysed.

☐ I understand that taking part will include being recorded (audio/video) and that the collected data will be analysed.

☐ I understand that my personal details such as name will not be revealed to people outside the project.

Consent for data publication, retention and sharing

☐ I understand that transcripts or excerpts of my interviews or recordings may be used in publications, reports, webpages, and other research outputs, providing that personal information such as name and email address will not be revealed.

☐ I understand that the data will be securely preserved for additional research after the end of this study and that other researchers may: (1) have access to the collected data and (2) use transcripts or excerpts in publications, reports, presentations, and other research outputs, but ONLY if they agree to preserve the confidentiality of the information as requested in this form.

______________________________	__________________________	_____________
Participant’s Name (Printed)	Participant’s signature	Date
__________________	__________________________	_____________
Researcher’s Name (Printed)	Researcher’s signature	Date

Appendix D

Demonstration Session Feedback Form

Virtual Environment Feedback Form

Your responses will be securely and anonymously archived and used in the research of virtual environments for brain injury rehabilitation. Data extracted from these responses may be used during presentation at conferences, published within academic papers, or other research outputs.

About You

1. How long have you worked in brain injury rehabilitation? ________________

2. What is your current role? ____

3. Have you had any other roles or experience in rehabilitation? _____________

____

4. Are you familiar with the Clinical Model of Executive Dysfunction as defined by Sohlberg and Mateer? ____

5. Are there any other models of executive dysfunction or brain injury that you regularly use? ____

____

About the Virtual Environment

1. Do you see any potential utility for this platform? _______________________

____

____

____

2. What could you learn about service users and their behaviour by using this platform? ____

____

____

3. Is this a platform you would engage with? ______________________________

____

4. What limitations would prevent you from using this platform? ____________

____

____

____

5. What risks do you see in using this platform? ___________________________

____

____

____

6. Would you be prepared to take these risks to undergo assessment and therapy in a virtual environment? Yes ☐ No ☐

Please elaborate: ____

____

7. What would make this platform more appealing to use? _________________

____

____

Any other comments? ____

____

____

____

Appendix E

Feedback from Clinical Professionals

Table E.1: Feedback from clinical professionals on the utility and appeal of Virtuality Street

#	Do you see any potential utility for this platform?	What could you learn about service users and their behaviour by using this platform?	Is this a platform you would engage with?
BIRT1	Assessment; rehabilitation of reclaiming lost skills; errorless learning; instant feedback and ability to record useful for building insight	Visual scanning; planning; memory; impulsiveness	Yes
BIRT2	Roleplay; practice	Cognitive functions; awareness of traffic; social interactions	Yes
BIRT3	Assessment of abilities in situations that would otherwise have too much risk	Reactions to situations and how to support these	Yes – with severely dysexecutive SUs
BIRT4	Assessment; teaching	Deeper understanding of abilities; boundaries that lead to confusion/distress	Yes

Continued on next page

Table E.1 – *Continued from previous page*

#	Do you see any potential utility for this platform?	What could you learn about service users and their behaviour by using this platform?	Is this a platform you would engage with?
BIRT5	Assessment; rehabilitation	Cognitive difficulties; triggers/potential risks in the community; reactions to changing situations and unanticipated interactions	Yes
BIRT6	Enabling people with limitations or community access restrictions to practice skills	Co-ordination of complex activities; interpersonal interactions; navigation under constraints (e.g. road safety)	Yes
BIRT7	Yes	Interactions with the public; reactions to difficult people; ability to orientate themselves; ability to complete daily tasks	Yes
BIRT8	Yes	Potential risks; understanding progress through rehab	Yes
BIRT9	Assessment; training; practice; gradual exposure to difficult situations. Would be interested in how behaviours in VR translate to predict behaviours in real life.	Response to challenging situations to minimise risks, e.g. lots of SUs get agitated in busy environments	Yes
BIRT10	Used before going into the community; continuous sessions; increasing task difficulty alongside real practice	Planning; executive functioning	Yes

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Table E.1 – *Continued from previous page*

#	Do you see any potential utility for this platform?	What could you learn about service users and their behaviour by using this platform?	Is this a platform you would engage with?
BIRT11	Road safety; social interaction; task planning. With tweaks could support: relaxation; mood stabilisations; helping people bedbound or with community access restrictions.	SU ability to measure risk; social situations; reaction to unexpected stimuli; how they complete tasks	Yes
HOSP1	Yes	Social interactions; planning tasks	Possibly
HOSP2	Physical balance; navigation; vestibular rehab; noise and visual stimulation	Social interactions	Yes
HOSP3	Reducing risk; improving insight and coping mechanisms	Feelings	Could be used if risk is managed
HOSP4	Problem solving; communication	Social interactions	Yes
HOSP5	Enabling people with limitations or community access restrictions to experience situations	Reactions to situations before trying them in real life	Yes
HOSP6	Community access; cognitive rehab; social interaction	Interactions with the world; where they look	Possibly
HOSP7	Feedback on errors; road safety; recording social interactions	Response to sensory stimulation; awareness of risk (driving, road crossing); social interactions; problem solving and self monitoring	Yes
HOSP8	Managing risks before going into the community	Strengths/weaknesses and provision of strategies before trying them in the community	Yes

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Table E.1 – *Continued from previous page*

#	Do you see any potential utility for this platform?	What could you learn about service users and their behaviour by using this platform?	Is this a platform you would engage with?
HOSP9	Yes	Social interactions; social awareness; decision making	Not within my field of rehab [exercise rehab] but good for others
HOSP10	Yes	Assessing safety of SU in controlled VR conditions	Yes
HOSP11	Cognitive functions in a safe environment	Responses; inhibition; initiation' safety awareness	Better for OTs
HOSP12	Controlled assessment and grading [varying task difficulty]	Understanding their difficulties and how to build strategies	Occasionally
HOSP13	Anxiety; fatigue management; executive functioning; vestibular issues; behaviour	Interaction with the technology	Yes

Table E.2: Feedback from clinical professionals on the risks and limitations of Virtuality Street

#	What limitations would prevent you from using this platform?	What risks do you see in using this platform?	Would you be prepared to take these risks to undergo assessment and therapy in a virtual environment?	Please elaborate:
BIRT1	Some service users may be reluctant, may find experience over stimulating or confusing	Possible risk of disorientation or falls (dizziness)	Yes	Possible risks are fairly minor if properly monitored
BIRT2	N/A	Not sure, possible epilepsy trigger	Yes	If SUs don't have any medical conditions
BIRT3	With regards to communication, the technology misses out the nuances of interacting with another person, i.e. facial expression and body language	The SU would be learning skills in the VR 'world' and this wouldn't be realistically representing their community at home. Are skills completely transferrable?	Yes	In a long term rehabilitation case where there would be enough time to successfully transfer skills.
BIRT4	Size of headset may put someone off	May disorientate/give false information	Yes	
BIRT5	-	-	-	-

Continued on next page

Table E.2 – *Continued from previous page*

#	What limitations would prevent you from using this platform?	What risks do you see in using this platform?	Would you be prepared to take these risks to undergo assessment and therapy in a virtual environment?	Please elaborate:
BIRT6	Space - ideally the person walking would be able to move more freely.	i) Collisions in the room; ii) Motion sickness; iii) Disinhibition of aggressive responding	Yes	All potential risks could be pre-assessed and monitored
BIRT7	Felt dizzy at the moving about part when standing	Mainly from the standing and moving about	Yes	-
BIRT8	-	Mobility/eyesight issues?	-	-
BIRT9	Ensuring the environment runs smoothly, if glitches SU more likely to become frustrated/disengage	No major depending of SU using	Yes	Probably more for therapy than assessment unless evidence that risks translate
BIRT10	-	People standing and walking around with the headset on	Yes	Training on how to use and to teach I would participate in

Continued on next page

Table E.2 – *Continued from previous page*

#	What limitations would prevent you from using this platform?	What risks do you see in using this platform?	Would you be prepared to take these risks to undergo assessment and therapy in a virtual environment?	Please elaborate:
BIRT11	Cost of equipment, how limited the range of applications available for VR. The SU's reaction to it.	The selection of participants would have to be very careful and careful observation as even high functioning TBI participants may become confused, disoriented or may become distressed.	Yrs	-
HOSP1	Require both sides of conversation if videoing for feedback	Link with seizure risk?	No	Need medical clearance
HOSP2	Motion sickness, over-sensitivity of movement	-	Yes	Would need a bucket at the ready
HOSP3	Consent	Dizziness and becoming self-conscious	Not sure	
HOSP4	Time taken to set up and program	Maybe tripping. Resulting feelings of nausea. Risk of damage to equipment	Yes	

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Table E.2 – *Continued from previous page*

#	What limitations would prevent you from using this platform?	What risks do you see in using this platform?	Would you be prepared to take these risks to undergo assessment and therapy in a virtual environment?	Please elaborate:
HOSP5	Nil	Seizures, dizziness	Yes	Within a controlled environment
HOSP6	Patients with visual dependence for balance, patients with visual processing problems, visual vertigo, or visual vestibular mismatch (like motion sickness), which is very common in traumatic brain injury	Seizure risk. Increase in vestibular symptoms/visual vertigo	-	On a case by case basis. It would have to be evaluated carefully.
HOSP7	Epilepsy patients. Providence for carry over into daily functions in the community	-	No	Not in seizure risk patients but in other TBI patients, yes
HOSP8	-	-	-	-
HOSP9	Epilepsy, early stage brain injury, injury to head - comfort	Seizures, anger/outburts from patients, patient understanding	Yes	Always open to new ideas and treatments that can assist the patient

Continued on next page

Table E.2 – *Continued from previous page*

#	What limitations would prevent you from using this platform?	What risks do you see in using this platform?	Would you be prepared to take these risks to undergo assessment and therapy in a virtual environment?	Please elaborate:
HOSP10	Risk of anxiety or seizure	-	Yes	In **** we are used to controlled risk with patients
HOSP11	Seizure risk	Seizure risk	-	Very patient dependent + level of risk
HOSP12	Has to be the appropriate patient. Not suitable for all.	Fine for the right patient. For patients who it is risky for, wouldn't do this	-	Depends on the patient
HOSP13	Space, vestibular issues, seizure risk	Seizure risk	Yes	If medical restrictions are allowed

Table E.3: Feedback from clinical professionals on making Virtuality Street more appealing to use

#	What would make this platform more appealing to use?	Any other comments?
BIRT1	More time and training with system, wider range of application (tasks)	Excellent first steps, think it's great
BIRT2	Not sure, possible practice experience or game format	-

Continued on next page

Table E.3 – *Continued from previous page*

#	What would make this platform more appealing to use?	Any other comments?
BIRT3	More representative of the SU's home environment. More control over interactions the SU would be having.	I believe that for clients with higher functional abilities, this type of technology would not be appropriate as real-life situations are best. However for those who require practice of these skills in a safer environment, it could work.
BIRT4	The ability to move around (walking)	
BIRT5	-	
BIRT6	i) Metric of safety in road crossing; ii) More avatars to interact with	A great development in the toolset available to rehabilitation providers
BIRT7	Cable at the back is a bit heavy and thick	
BIRT8	-	
BIRT9	I would prefer microphone ”real” response than computerised	Interested in eye tracking. Would be interested to see this platform used across a range of disciplines as can be adaptable for OT, psych + SLT
BIRT10	Tasks. Rewards maybe?	
BIRT11	I found the wire on the headset distracting	I felt that adding game elements such as points of health/lives would massively broaden the scope of this tool as this would lead to motivation/risk factors being assessed, used and hopefully something that could be trained in the participant.
HOSP1		
HOSP2	Wheelchair users/access to community	Thankyou
HOSP3	Sensors and more interactions	Very interesting, particularly possible future applications

Continued on next page

Table E.3 – *Continued from previous page*

#	What would make this platform more appealing to use?	Any other comments?
HOSP4	A good selection of pre-programmed scenarios	A very promising cognitive rehab tool
HOSP5	Being able to experience work-specific situations, i.e. office, gym, in outdoor settings	
HOSP6	More literature/evidence	
HOSP7	Is there potential for a wireless headset? An office environment	
HOSP8	-	-
HOSP9	-	-
HOSP10		
HOSP11	Use of eye gaze	
HOSP12	Easier to set up	
HOSP13		