Designing Virtual Environment Interface for Cognitive Rehabilitation of Executive Functions

submitted by

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Summary

This research project describes a virtual environment interface for use in cognitive rehabilitation of executive functions in brain acquired injury patients. It expands on previous development of an immersive virtual environment by Zack Lyons. The research will introduce an interface for use by therapists to manipulate the virtual environment such that it can conduct cognitive rehabilitation compared to real-life environments where resources are limited. This allows therapists to assess and train their clients without causing harm or disturbance to others or themselves. The research project involves the development of an interface that allows clinicians to set the simulation of an assessment for executive functioning in a realistic setting. In addition to the use of a semi-autonomous dialogue model, it would provide a realistic social environment for patients to perform tasks involved. A qualitative research with patients to evaluate the environment and expert review from clinicians to validate the virtual environment will be conducted.

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Chapter 1

Introduction

In this chapter, the research area and direction will be described to put forward the importance and relevance of contributions the research will bring.

The research in this dissertation describes developing an immersive environment in virtual reality for therapists to assess and provide therapy for patients with acquired brain injury that has affected their executive functioning.

In Chapter 2, previous work related to cognitive rehabilitation in ABI patients will be discussed. Appendix A contains the outline of the planned approach for the project, including the allocation of time and resources needed for completion of the dissertation.

1.1 Problem Description

Acquired brain injury (ABI) is known as one of the most common causes of death and disability in children and adults [DMC*12]. It is defined by an injury to the brain that occurs after birth. As such, disorders and disabilities from birth are not considered, including progressive conditions such as dementia are not within the scope of ABI. The most two common causes of ABI are traumatic brain injuries and stroke [Mar17]. ABI is known to severely hinder a person's cognitive, emotional, physical, psychosocial, neurological and behavioural functions [GJK*17]. Among these problems, patients with ABI frequently suffers from cognitive impairments involving language, reading, memory, executive functioning, and attention [Wil02]. Executive functions can be perceived as a core element in cognitive functioning especially since the deficiency is one the most common causes of disability after ABI [LSO*11].

In the United Kingdom, there is a gradual increase in patients with acquired brain injury in recent years and statistics indicates that there is at least one person admitted to hospital for an acquired brain injury every ninety seconds [Hea15]. Furthermore, ABI patients are more likely to have social problems such as committing an offence in society due to their condition. In fact, Huw Williams claimed that over 60% of those in prison has a history of traumatic brain injuries. Due to the nature of hindrance of cognitive abilities, they are also more likely to repeat their offences and impose a high maintenance cost for crime and legal issues.

From the above mentioned issues, there is a need for enhancement towards therapy in cognitive rehabilitation due to the gradual increase in number of ABI patients that would need to cope with severe long term effects reducing their quality of life such as poor integrations [GJK*17] and poor memory [YM09]. Besides that, there is a limited resources available in the country and together with the increased demand of therapy. Thus, it is important to address the issue by having more effective cognitive rehabilitation therapy and a focus on executive functioning as it is one of the main areas that attribute to the cause of repeated crime offences and social problems.

1.2 Context

Today, rehabilitation rely on both neuroimaging and neuropsychological assessments to identify deficits in clients with ABI and later arrange for cognitive rehabilitation strategies targeted at those deficits. However, there are difficulties in assessing the "hot" executive functions due to the involvement of social interactions that may impose harm or disturbance to themselves or the people in the surrounding. As such, therapists face a problem with bringing ABI patients into the real world for training due to the neuropsychological effects of their injury. This leads to patients requiring constant supervision and may need more than one social worker out with them which poses a problem as there is a high demand of human resources and a high risk exposure as well as a high maintenance cost.

1.3 Research Aim

To tackle this problem, a safe and controlled environment for cognitive rehabilitation can be provided to the ABI patients with virtual reality. Building on previous work in virtual reality for mental health, the research proposes that the virtual environment will be able to imitate real-world settings and allow specialists to carry out assessments and training facilities with the ability to manipulate the environment personalized for their client based on the severity of injury faced by their clients. Besides that, there is a lack of VR programs targeted at cognitive rehabilitation [Lar17] which gives a room for research in the area and to give an insight of future guidelines for this kind of programme.

This is managed by the ability to control or guide emotions of patients with ABI through the social interactions of avatars in the environment. As there is a lack of virtual reality programmes targeted at cognitive rehabilitation [Lar17], current research will contribute to future guidelines for this kind of programme.

1.4 Research Objectives

With the research aim outlined, the research dissertation proposes further extension of the virtual environment developed by Zack Lyons [LBCS*15]. The proposed project aims to primarily develop an interface in the virtual reality environment for therapists to carry out assessment in a safe and controlled environment with the execution of Multiple Errands Task. Besides having to complete tasks heavy on cognitive load, the environment will aim to draw out certain emotions that would affect decision making and social behaviour of the patients with ABI. While the environment introduce distractions to the patients to divert their attention from the task available in the environment, patients will have to engage in social interactions that would be able to help or hinder them from completing the task under the control of a therapist. The therapist would be able to control the virtual environment through a pre-defined quantity of distractions adjusted prior to a session to adjust the level of difficulty for the patient based on factors that predict performance such as age and nature of brain injury [Wil02]. Besides that, they would be able to observe clients' social behaviour by guiding conversations held with avatars in a semi-autonomous dialogue model during the rehabilitation session. Through this user interface of adjusting distractions and controlling dialogues taken place in the environment, the therapist will be able to assess and outline rehabilitation strategies for the client with a reference to a data visualization that shows the patient's performance.

The following objectives outline the direction in which the proposed research will take.

1.4.1 Design

Using image editing software, low fidelity prototypes will first be generated with reference to the existing environment. By evaluating the prototypes with the therapists, flexible changes can be made with the use of scenario cases therapists provide. At later stages, high fidelity prototypes can be evaluated to manage the visual aesthetics and change requirements. The class architecture can be designed with LucidCharts after looking at Unity's documentation on its interfaces and plugins available. The design stage uses a user-centred design approach that would undergo iterations of prototyping while initial development is going on before final designs are set. After that, focus will be put on development before further testing and evaluation.

1.4.2 Development and Testing

The program will be developed on Unity. For therapists, it is important for a therapist to be able to manipulate the environment without discounting the realism of the virtual world. In the process of assessment, it is recommended that the environment can be manipulated such that the level of difficulty can be altered and to provide distractions based on the patient's real-time behaviour. Besides that, the therapist will be able to control social behaviour exhibited by avatars in the virtual environment to observe and guide the emotions of patients. To do so, a user interface for the therapist to use will be displayed on a second screen display.

User Interface for Therapist

For the therapist to manipulate the environment, a user interface will be developed on a second screen display such that a therapist can easily point and click the options to adjust the environment based on attributes that would affect a patient's performance. These include age, gender and nature of the brain injury such as severity, extent, and location [Wil02]. Prior to a session, the therapist can manage the settings for a difficulty personalized to the patient and be able to change it during the session as well.

Manipulation of Environment

To adjust the level of difficulty, a therapist will be able to change the number of cars appearing in the environment. Besides that, the therapist will also be able to set the number of tasks for the patient to complete. Other distractions will be the amount of noise in the environment and the amount of people on the streets. These distractions are meant to increase the cognitive load on the patient such that the assessment of their disability can be accurately conducted.

Control of Avatars

To assess social behaviours, the therapist can control the avatars placed in the environment. This will have two modes in which an avatar would be supportive towards the patient, and the other being impolite such that a patient would be frustrated for assessment of emotion regulation. This is very useful as most assessments currently used in real life do not assess the "hot" executive functions. Facial expressions and body language would then be reflected on the avatar through the two different modes set for a realistic conversation to take place.

Data Visualization

Currently, the system collects data from the environment and is exported as a large comma-separated values (CSV) file. Using the existing foundation of the data visualization, it may be possible to have the data visualized in a video form to see the pathways the patients have taken and to observe pattern. This would also allow patient to self-monitor their performance and help raise insight. Besides that, the therapist would be able to review and compare the visualizations to decide the next steps in cognitive rehabilitation.

Evaluation

Ongoing evaluation with the prototypes would take place at the initial stage of design such that iterative adjustments can be made. Interviews with clinical psychologists would be helpful for gathering the requirements and information on how assessments are currently conducted and gathering measures for "hot" executive functions. Furthermore, a qualitative research in the form of natural testing will take place during the final testing stage after a session is conducted between a therapist and patient. After having consent from both parties, notes will be taken from observation as well as interviews with the therapists and patients separately and also jointly to get different insights on the effectiveness of the system.

Ethical Considerations

As the project deals with a vulnerable population, ethical considerations over their mental well-being is crucial. An ethical review of the system imposed on the users as well as the data being collected would be taken into consideration. Under the supervision of a therapist, the therapist would be informed the right to stop the session at any point during the simulation in the care of the patient's physical and mental well-being.

Chapter 2

Literature Review

This chapter is a comprehensive literature review on the relevant concepts, previous work and achievements that will help to build the foundation of understanding of the field that will provide an overview of motivation in the research.

2.1 Models of Executive Function

Noted in previous chapter, ABI hinders cognitive, emotional, psychosocial, and behavioural functions. The most affected area is the executive functions in which ABI often causes functional impairments [MFS02]. An understanding of executive functions will help to design the infrastructure used in the cognitive rehabilitation approach used for the project.

Executive functions is further divided into two processes of "cold" and "hot". The "cold" process involves the use of rationality and logic while emotions are involved in the "hot" process that is responsible for decision making [FZC*12]. While studies have not found a strong relationship between "hot" and "cold" executive functions [FZC*12], an assessment of both aspects would be helpful for clinical psychologists to evaluate which approach to take next. These processes are further categorized and summarized in Figure 2-1.

Several models have been developed to show specific items covered by executive functions shown in chronological order in Figure 2-2. Most of these models relates to "cold" executive functions with the exception of Damasio's Somatic Marker Hypothesis [CSTC08, MFS02].

In Luria's model of mental process (1973), he has divided the brain into three main units with the first unit comprised of the brain stem, second unit of temporal, parietal and occipital lobes, and the third comprised of the frontal lobes [CSTC08]. Each of

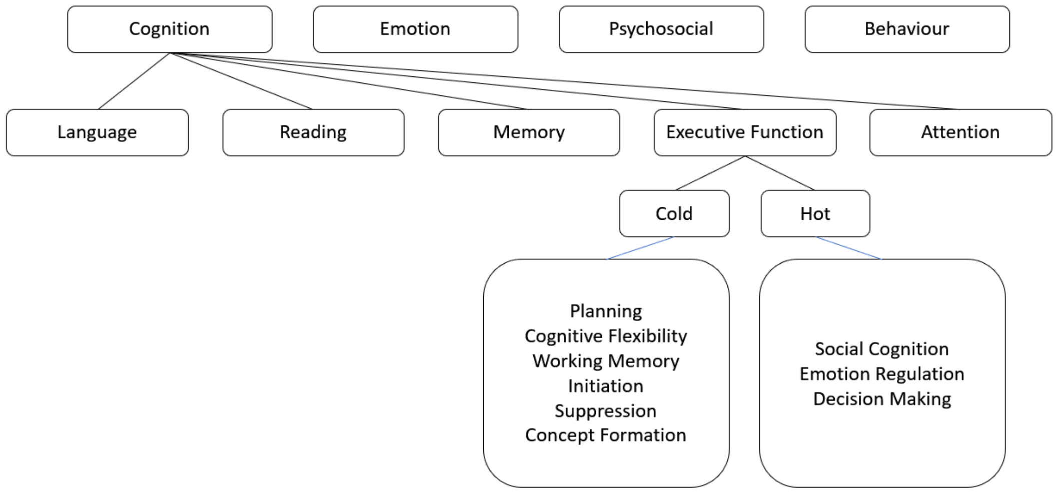

Figure 2-1: Framework of Executive Function Processes in Areas Affected by ABI. *Adapted from:* [GJK*17, HHLZ05]

these units are responsible of different cognitive and behavioural functions. In the first unit, it is responsible for the regulation and maintenance of arousal. In the second unit, it is described to be for encoding, processing, and storage of information. The behaviour control takes place in the third unit.

In Duncan's goal neglect theory (1986), he proposed that behaviour is goal-oriented in which actions are taken in terms of goals and subgoals. These goals activate and inhibit the behaviour that would encourage or demote completion of a task. It is the base principle of Goal Management Training used in training for ABI patients [CSTC08].

In Norman and Shallice's supervisory attentional system (SAS) model (1986), they have described that human behaviour involves two systems of contention scheduling and supervisory attention. In contention scheduling, learned behaviours are carried out but in supervisory attention, it is responsible for carrying out novel tasks. Executive functioning is encapsulated by planning or decision-making, troubleshooting, anticipation of danger, sequencing, and inhibition or suppression of behaviour [CSTC08]. The model was later extended by Burgess and colleagues (2000) with an additional multitasking component [CSTC08].

Stuss and Benson (1986) proposed a tripartite model in which there are three systems, with the first two systems involved in maintaining attention, and the third system for executive control in attention [CSTC08]. They further explained that the model would have a relation with SAS. The model focuses on how damage can result in the

Luria (1966)	Duncan (1986)	Norman and Shallice (1986)	Stuss and Benson (1986)	Damasio (1995)	Lezak (1995)	Sohlberg and Mateer (2001)	Keil and Kaszniak (2002)
Anticipation	Activation	Initiation	Initiation	Working memory	Volition (includes self-awareness and self-monitoring)	Initiation and drive (starting behaviour)	Planning, scheduling, strategy, use, rule adherence
Planning	Inhibition	Consolidation	Planning	Attention	Planning	Responsive inhibition (stopping behaviour)	Generation, fluency, initiation
Execution	Memory	Regulation	Sequencing	Language comprehension and expression	Purposive action	Task persistence (maintaining behaviour)	Shifting and suppression
Self-monitoring		Inhibition	Organization		Effective performance	Organization	Concept formation and abstract reasoning
			Regulation			Generative thinking	
						Awareness (self-monitoring and self-modifying)	

Figure 2-2: Summary of Executive Functions Models. *Adapted from:* [CSTC08, Pur11]

loss of consciousness and other impairments.

In Damasio's somatic marker's hypothesis (1995), emotion and social behaviour is emphasized in the role of decision making [CSTC08]. He accounted emotion being mediated by prefrontal lobes and that patients with a ventromedial frontal cortex lesion would be incapable of linking their behaviour with a somatic signal despite having understood the consequences of an inappropriate behaviour. Thus, without making use of those emotion-related somatic markers, patients with lesions in these regions would be unable to regulate their behaviour.

In Lezak's model (1995) , it contains four components that is similar to Luria's model (1973) which are volition, planning, purposive action, and effective performance [Pur11]. The model proposes executive dysfunctions as a disassociation between knowing a problem and carrying out the solution.

Sohlberg and Mateer's model (2001) is used in the clinical context in which observations, management plan, and assessment are guided [Pur11]. The model does not only consider initiation, maintenance, and suppressing of behaviour, but also generative thinking in terms of idea generation. An interesting element is awareness that covers self-monitoring and insight [Pur11]. Previous models have not considered insight, the awareness of their own behaviour and deficits in performance.

Based on these models, the research approach hopes to assess both "cold" and "hot" processes which ideally would be incorporating both Sohlberg and Mateer's model (2001) with respect to regulation of behaviour, thus the addition of distractions into the environment and Domasio's somatic marker's hypothesis that focuses on emotion which would help in assessing social cognition. In fact, studies have found an association between emotion cognition and awareness with impact on rehabilitation treatment [LFBS17]. Therefore, the selected models form a core concept for the assessment of executive function in the research.

2.2 Cognitive Rehabilitation of Acquired Brain Injury

Following the understanding of the definition and importance of executive functions, this section will describe cognitive rehabilitation approaches that are used to help recover or improve executive functioning in patients with ABI.

To help compensate for the impact of the difficulties faced by these patients, cognitive rehabilitation is most commonly used by clinical psychologists to help improve their performance. This is because after an ABI, the brain cells are not regenerated unlike other cells in the body [Hea15].

In cognitive rehabilitation, the general structure of a provisional model is described as a series of assessment, recovery strategies, evaluation, and re-assessment [KD09]. Generally, there are two different approaches for recovery which are the *remedial approach* and *compensatory approach* [Wil02]. These approaches differ in how they drive the brain of the patients in learning new skills [Mar17]. In a *remedial approach*, individuals go through repetitive exercises as a means of training to relearn a functionality they lost. In the *compensatory approach*, individuals adapt to their current situation, without recovering the performance they once had. For a recovery to take place in the *compensatory approach*, it makes use of the concept of "neuroplasticity" which relies on the flexibility of the brain to reorganize itself to minimize the impacts of brain injury and learn alternative methods in coping with other remnants of disabilities [Hea15].

The cycle of repeated assessments shows that it is an important element in cognitive rehabilitation. In fact, clinical psychologists report that there are anomalies in their performance between neuroimaging and neuropsychological assessments. For example, patients may have a disability in doing a particular task even though the scans from functional magnetic resonance imaging (fMRI) may not show a brain lesion. Furthermore, there are occurrences when patients would pass specific assessments that isolates particular functioning but fail in assessments that are brought together. Due to the complications of ABI, a combination of psychometric tests, observations and standardized ratings are mostly required for accurate assessment to better comprehend the pace of natural brain recovery and the effects of rehabilitation strategies. Among these methods, observations are usually difficult to assess as patients has to be taken to the real-world with their psychosocial impairments, yet it is important as it gives therapist an insight to how patients would deal with those situations and assess the kind of difficulties they face.

2.3 Neuropsychological Assessments of Executive Functions

According to the framework adopted by World Health Organization (WHO), there are three main concepts for neurological assessments, which are *impairment*, *disability*, and *handicap* [SM14]. While *impairment* focuses on specific physiological functions such as speech and memory function, *disability* focuses on specific functional abilities such as the communication needs of speech and remembering to do a certain task. Assessments captured by *handicap* is focused on the social and role function resulted from disabilities. Based on these definitions, the concept that will be focused on is *disability* as it focuses on specific tasks to be carried out and mostly has a constrained environment difficult to be carried out in real-world settings.

Having the framework of assessments used in neurological disorders, neuropsychological assessments can be classified based on the properties of which they are assessing. In measuring executive functions itself, there are several specific assessments that focus on single cognitive abilities such as attention and memory or learning [SM14]. With the current research direction, observational methods will be discussed as they are challenging in the real environment but possibly safer and more convenient in a virtual reality environment.

Figure 2-3 summarizes the assessments used in the assessment of executive functions that classified the different types of test and a description is given. Certain descriptions were taken out as the structure may differ between sessions or they are common tests.

Based on the research aims, the assessments considered in the environment will target those with an observatory method with a naturalistic or constrained environment. Among the choices includes but not limited to the Six Elements Test and Multiple Errands Task developed by Shallice and Burgess in 1991, Executive Function Route-Finding Task developed by Boyd and Sauter in 1994, and Greenwich Test [SM14, CSTC08] which are open-ended and allows observation from the therapist.

The Multiple Errands Task involves an individual completing a set of tasks in a naturalistic environment which involves rule adherence, information processing, planning, and other executive functionality [CSTC08, SM14], Usually, a therapist would passively observe the patient and thus, provides opportunities for the therapist to manipulate the environment to further observe the interaction of the patient with the surroundings.

Furthermore, different activities can be added or altered in the environment based on this task which will allow chances for other activities to take place and allow assessment of the "hot" executive functions through social interactions placed in the environment. It is also reported to have high predictability for independent functionality and a good predictor of rehabilitation effects [SM14]. As such, the research will build on the task with expectations to assess both "hot" and "cold" executive functions.

2.4 Virtual Reality in Cognitive Rehabilitation

As previously discussed, virtual reality opens up the possibilities of observatory assessment methods as it can be built to imitate real world settings and addresses cognitive and behavioural functioning issues.

Virtual reality (VR) is mostly known for its characteristics of providing presence, involvement, immersion, and immediate feedback. As such, it is a desirable environment to develop rehabilitation in. Many researches conducted emphasise on the assessments of memory, attention deficits, and executive functioning impairments. There is a common limitation of cost and availability of creating the virtual environment [Par15]. Although there could also be ethical challenges or the assumption of not needing a clinician in future development, gamification factors of the environment as well as the ability to get real-time feedback on the patients' performance could overweight the weaknesses of using VR [RK05]. Moreover, it is a safer environment in which the complexity can be customised to the patient [Lar17] and be manipulated under control. In addition, there has been reports of significant improvements in patients being projected in real world after rehabilitation strategies have taken place in VR [YM09, RBR05, Par15]. Most importantly, it enhances the ecological validity of assessments with the possibility of replication within different contexts and environments. In fact, numerous environments have been developed to imitate real life functioning including supermarkets, homes, kitchens, school environments, and cities [RK05, FASI]. Based on previous research [RSF*16], cognitive rehabilitation in VR has also shown to be more effective compared to traditional approaches which justifies the approach of the research towards virtual reality.

To give an outline of VR, there are three main types of VR which are immersive, semi-immersive, and non-immersive [Lar17]. In an immersive VR environment, the user is equipped with a headset and replaces their physical space with the perception of a virtual environment. These environments usually invoke self-reports of simulator sickness which is a disparity between the visual aspects of peripheral vision and kinaesthesia [Par15]. Semi-immersive VR involves just the projection of a virtual environment without hindering the sight of the real world. In an non-immersive VR, the user interacts with the virtual environment passively and does not need physical movement to navigate in the environment but relies on an interaction device such as a keyboard or trackball.

Primarily for this research, an immersive VR is used to give a sense of real world situations. Although there are no reports of existing complications with the use of the existing environment, the vulnerability of the patients should not be neglected. Despite that, the use of such technology on the population would contribute to the research area on where the simulator sickness may come from as the population suffers from varied levels of injuries and in different areas of the brain. Furthermore, the use of immersive VR can simulate realistic situations that allows ecological validity as well as dynamic assessment and training [Par15].

2.5 Social Dialogues

To incorporate social interactions within the environment, the research proposes the use of social dialogue models for Non-Player Characters (NPCs) found in games as they are meant for motivation and enhance the experience of the environment for the player [Bru14]. A NPC may also act as a barrier for a player achieve a specific goal [Bru14] which aligns with the objectives of the research.

To make these characters believable, it has been suggested that humans tend to perceive computers and other systems as humans with the phenomenon known as "media equation" described by Reeves and Nass in 1996 [Bru14]. With the use of gestalt theory on recognizing patterns, even if the NPC is inadequate, human perception will see it as a familiar human. This means that despite the visual appearance of the avatar may not look realistic, it would still be familiar to the patient with ABI as almost a real person due to its likeliness of appearance.

In terms of social interactions to be held by the avatar with the patients, a proposed model by Trenor and colleagues [TMS16] suggested that social practices are made up of linked stages, actions , performance, and event stage. Linked stages are described to be a series of actions containing a performance, in which a performance is a specific action carried out by the character such as a dialogue or animation of gesture. These elements are mediated by a social schema which is comprised of abstract representations of the character. For example, the type of relationship the character has with the character and attributes the character holds. Based on their model, there is a scoring method for how a NPC will react. This scoring method takes into account of the way social norms are introduced, a microtheory and influence roles that contains the representation of the social interaction and scoring weight. They have also devised that a social interaction would end when there are no more linked stages after an action a character takes. This model will be helpful for the available speech produced by the virtual avatars in the environment manipulated by the therapist.

As the research aims to guide emotions, impoliteness of the NPCs should be considered. Besides improving believability of the environment, impoliteness can add engagement to the player in the environment. Following Culpeper's notion that a speaker would become rude if verbally attacked by impoliteness and aggressive behaviour would show when confronted with fear or anger emotions, the NPCs would show such behaviour to assess the inhibition control of the patient [CS09]. Campano and Sabounret's model (2009) incorporates emotions, register, personality, and social relations for impoliteness. Following their model, the register is a social distance between two parties that incorporates the use of language in a particular social setting, and personality is associated with agreeableness that moderates anger emotions in a person. Social relations are tied to the dominance the NPC has in the context and liking towards the character.

Using such models, the NPC can be outlined to create a believable social interaction with the patient with ABI and be able to draw out emotions for the therapist to assess "hot" executive function processes.

Type	Test	Theory	Target functionality	Description
Virtual environment	Jansari assessment of Executive Functions for Children (JEF-C) (Gilboa et al., 2017)		Planning, prioritisation, selective thinking, creative thinking, adaptive thinking, prospective memory	A child (age 8-18) has to prepare for a birthday party with parents' absence in a VR environment
Clinical rating	Behaviour Rating Inventory of Exeutive Function (BRIEF, Gioia, Isquith, Guy, & Kenworthy, 2000)		Inhibition, shift, emotional control – behaviour; Initiation, working memory, planning, organization monitoring	Parents rate their child on a 3-point Likert scale for 86 questions
Clinical rating/bedside assessment	Reciprocal Motor Programme Test	Luria's model of mental process	Motor; inhibition	Tap the hands once they hear two tapping sound and tap their hands twice when they hear one tapping sound
Clinical rating/bedside assessment	Fist-Edge-Palm-Test	Luria's model of mental processes	Frontal-executive functions (may activate other regions as well)	Place hands in each of the postures and alternate as quickly as possible
Clinical rating/bedside assessment	Cambridge Neurological Inventory (Chen et al., 1995)	Luria's model of mental processes	Motor initiation, sequencing, inhibition	
Lab-based/constraint environment	Six Elements Test (Wilson et al., 1996) – incorporated into Behavioural Assessment of Dysexecutive Syndrome (BADS)	SAS model	Planning, strategy allocation and monitoring, inhibition/suppression	Complete three main tasks with two subtasks in each within 10 minutes without switching between sub-tasks (Simple arithmetic, written picture naming, dictation)
Lab-based/constraint environment	Behavioural Assessment of Dysexecutive Syndrome for Children (BADS-C, Emslie, Wilson, Burden, Nimmo-Smith, & Wilson 2003)	SAS model	Planning, novel problem solving, flexibility, perseveration	Water Test – problem solving; Zoo Map Test – planning; Six Part Test – planning, scheduling, performance monitoring
Lab-based/constraint environment	Greenwich Test (Burgess et al., 2000)	SAS model	Executive memory, planning and intentionality	
Lab-based/constraint environment	Tower of London (Shallice, 1982); Tower of Hanoi (Humes et al.,	SAS model	Planning	

Figure 2-3: Summary of Assessments Used To Test Executive Functions (1/4).

	1997; Newell & Simon, 1972)			
Lab-based/constraint environment	Strategic Self-Regulation Test	SAS model	Strategy allocation	
Lab-based/constraint environment	Multiple Errands Test (Shallice & Burgess, 1991)	SAS model	Strategy allocation, planning	
Lab-based/constraint environment	Hotel Test	SAS model	Planning, strategy allocation	
Lab-based/constraint environment	Hayling Sentence Completion Test (Burgess & Shallice 1996a)	SAS model	First part: initiation; Second part: suppression – For anterior lesions * Verbal inhibition	First part: complete end of sentences with a pre-potent response to make meaningful connection Second part: inhibit pre-potent response by providing irrelevant words to complete given sentences
Lab-based/constraint environment	Brixton Spatial Anticipation Test (Burgess & Shallice 1996b)	SAS model	Rule detection, impulsivity - Frontal and posterior lesions	Discover rules underlying the placement of blue circles among a grid of unfilled circles. After a pattern has been formulated, the placement rules changes (Similar to Wisconsin Card Sorting Test)
Lab-based/constraint environment	Sustained Attention to Response Task (SART, Robertson et al., 1997)	SAS model	inhibition, sustained attention	Computer-based task designed to measure a person's ability to withhold responses to infrequent and unpredictable stimuli during a period of rapid and rhythmic responding to frequent stimuli
Naturalistic environment	Dysexecutive Questionnaires (DEX, Wilson et al., 1996)	SAS model	Intentionality, inhibition, executive memory, positive and negative affect	
	ROtman-Baycrest Battery to Investigate Attention (ROBBIA, Stuss et al., 2005)	Tripartite theory	Attention	Simple reaction time task; Choice reaction time task; Prepare reaction time task; Concentrate task; Count

Figure 2-3: Summary of Assessments Used To Test Executive Functions (2/4).

				task; Divide task; Tap task; Switch task; NoGo task; Suppress task; Set task
Lab-based/constraint environment	Wisconsin Card Sorting Test (WCST, Heaton, Chelune, Talley, Kay & Curtiss, 1993)		Switching, perseveration, planning (Heaton 1981)	
Lab-based/constraint environment	Verbal Fluency Test		Verbal production	
	Cambridge Neuropsychological Test Automated Battery (CANTAB)	Working memory model		Computerized assessment package
Lab-based/constraint environment	Letter Number Span Test (Gold et al., 1997)	Working Memory Model	Online monitoring and sequencing	Respond to auditory presentation of a series of alternating numbers and letters by repeating the numbers from smallest to largest, followed by letters in alphabetical order.
Lab-based/constraint environment	N-back (Callicott et al., 1998)	Working Memory Model	Online monitoring and updating	Recall visual stimulus seen after N-position was previously presented
Naturalistic environment	Iowa Gambling task	Somatic Marker Hypothesis	Emotion and decision-making, inhibition (learning of reward and punishment)	Participants are presented with 4 virtual decks of cards on a computer screen. They are told that each deck holds cards that will either reward or penalize them, using game money. The goal of the game is to win as much money as possible. The decks differ from each other in the balance of reward versus penalty cards. Thus, some decks are "bad decks", and other decks are "good decks", because some decks will tend to reward the player more often than other decks.

Figure 2-3: Summary of Assessments Used To Test Executive Functions (3/4).

Virtual environment	Executive Golf Task (Morris et al., 1998)		Brain activation	Game of golf to put a ball according to a specified set of rules, into each golf hole presented on a touch-sensitive computer screen

Figure 2-3: Summary of Assessments Used To Test Executive Functions (4/4). *Adapted from:* [CSTC08, GJK*17, GJK*17, FZC*12]

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Appendices

Project Plan

The preliminary timeline for the research project generally starts from Task 2 of the research proposal process to the main research project submission date. The main tasks for the project is broken down into Design, Development, Testing, Evaluation, Data Analysis, and Documentation. Although the timeline comprises of activities that occur prior to the start of the main research project such as the research proposal and the learning curve in preparation for the main research project, they will not be discussed below as they are not the main concerns for the dissertation. The full Gantt Chart can be referred to in Appendix A.

Weekly Meetings

For the project, weekly meetings are conducted for an hour with the project supervisor. Joint meetings with the developer, Zack Lyons and another student (Liam Rundell) with a similar project would occur occasionally during these meetings to invoke more productive thoughts on the system.

Design Stage

Following a user-centred design approach, the design stage involves producing low fidelity prototypes with an iterative approach with potential stakeholders. Using a low fidelity prototype, clinical psychologists will be able to have their input in the requirements for the environment such as specific objects like a ball to be added into the environment as distractions. High fidelity prototypes will be produced during development for the visual aesthetics that would appeal to the therapists and patients with ABI. The class architecture for Unity will also be created with the specified requirements. Evaluation methods will also be planned and designed at this stage.

Development Stage

The development stage of the interfaces within the environment would take the longest time and is estimated to take place from May to the end of July to leave some time for testing and debugging the system environment. The implementation of different features of communication can take place in parallel to finish development on time.

Testing Stage

The testing stage is scheduled to be finished by early August so that the environment is ready to be deployed and evaluated. In this phase, participants can be recruited to do the initial testing.

Evaluation Stage

The evaluation stage is when participants including both therapists and patients with brain acquired injuries would test the system environment. Following the initial low fidelity prototype designs, evaluations can be carried out with therapists and patients continuously until the high fidelity prototype stages. As recruiting participants may take some time, the time estimated is to be about a month long to recruit and carry out evaluation tasks that can be comprised of one-to-one interviews and joint interviews with both the patients and therapists.

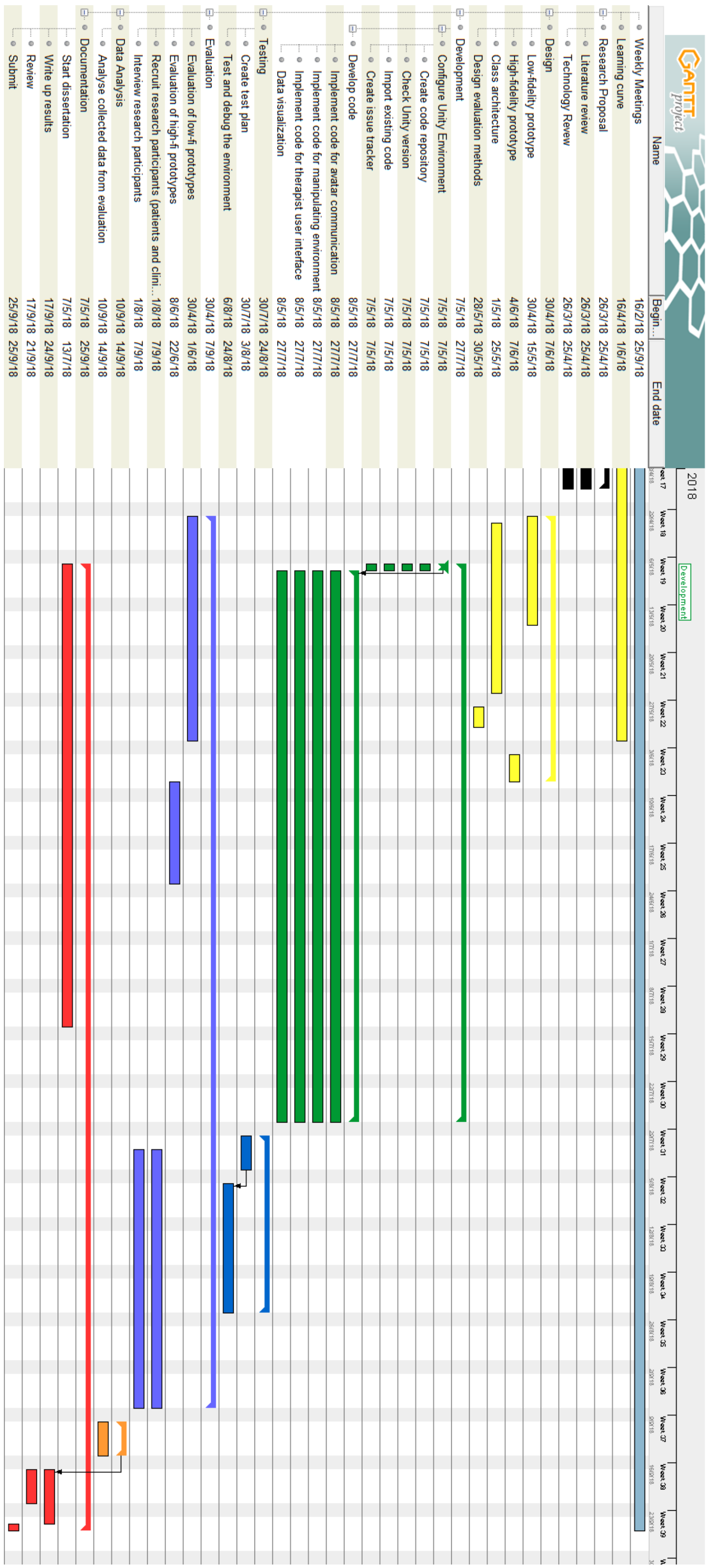
Data Analysis

The data analysis stage takes a week long to analyse the collected data from the evaluation stage by mid-September for the write-up of the dissertation.

Documentation

The documentation stage would initially start in parallel with the development stage after the research proposal with literature and technology review is done. This would save time for the later stages such that only the results and discussion sections can be filled in. Ideally, the dissertation would be reviewed by the project supervisor two weeks before submission so that it can be re-edited and be peer-reviewed several times before submission.

Timeline



GANTT project
2018
Development
Name
Begin...
End date
Weekly Meetings 16/2/18 25/9/18
Learning curve 16/4/18 1/6/18
Research Proposal 26/3/18 25/4/18
Literature review 26/3/18 25/4/18
Technology Review 26/3/18 25/4/18
Design 30/4/18 7/6/18
Low-fidelity prototype 30/4/18 15/5/18
High-fidelity prototype 4/6/18 7/6/18
Class architecture 1/5/18 25/5/18
Design evaluation methods 28/5/18 30/5/18
Development 7/5/18 27/7/18
Configure Unity Environment 7/5/18 7/5/18
Create code repository 7/5/18 7/5/18
Check Unity version 7/5/18 7/5/18
Import existing code 7/5/18 7/5/18
Create issue tracker 7/5/18 7/5/18
Develop code 8/5/18 27/7/18
Implement code for avatar communication 8/5/18 27/7/18
Implement code for manipulating environment 8/5/18 27/7/18
Implement code for therapist user interface 8/5/18 27/7/18
Data visualization 8/5/18 27/7/18
Testing 30/7/18 24/8/18
Create test plan 30/7/18 3/8/18
Test and debug the environment 6/8/18 24/8/18
Evaluation 30/4/18 7/9/18
Evaluation of low-fi prototypes 30/4/18 1/6/18
Evaluation of high-fi prototypes 8/6/18 22/6/18
Recruit research participants (patients and clini... 1/8/18 7/9/18
Interview research participants 1/8/18 7/9/18
Data Analysis 10/9/18 14/9/18
Analyse collected data from evaluation 10/9/18 14/9/18
Documentation 7/5/18 25/9/18
Start dissertation 7/5/18 13/7/18
Write up results 17/9/18 24/9/18
Review 17/9/18 21/9/18
Submit 25/9/18 25/9/18

Resources

Software

For the design part, tools such as InVision and LucidCharts can be used to create the low-fidelity prototype and class diagrams. These tools are readily available and are free to use on the web. In terms of high fidelity prototypes, screenshots from the environment can be captured and altered with image editing software such as Photoshop. The student already has such image editing software on a personal device. For the development part, an existing environment created by Zack Lyons will be required for adapting the system environment to run and test. It is developed in Unity 3D and the code would be written in the C# language. A code repository on Github would be created for accessibility for the supervisor as reference. Further considerations for the development is to use the free Nvidia VRWorks plugin for Unity.

Hardware

For the VR component, the HTC Vive headset and a pair of headset for both visual and auditory perception is required for deployment. A computer with the capability to develop, run and deploy the system is also needed. With the amount of storage and processing required to run the program, home devices may not be capable to run the program. There is a set-up currently available at 1 West 2.58 which can be used for development and testing. It is also possible to apply for a Graphic Processing Unit (GPU) Grant for free from Nvidia to conduct current and future research under the supervisor's application.

Participants

Participants with a brain acquired injury and clinical experts need to be recruited for the evaluation of the study. With the existing relationship of the supervisor with the Brain Injury Rehabilitation Trust, it is possible to recruit both volunteers and therapists from the organisation or other relevant associations. An alternative to the evaluation of the system is to recruit healthy participants from the university as a control group to test the system. Clinical psychologists from the Department of Psychology at University of Bath can then be asked to spare some time to evaluate the system.