AN INVESTIGATION INTO COMMUNITY TRAVEL PATTERNS, NAVIGATIONAL STRATEGIES AND VIRTUAL REALITY ROUTE LEARNING AFTER AN ACQUIRED BRAIN INJURY

by

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Abstract

Making a simple journey may appear to require very little planning on behalf of the navigator but it, in fact, utilises multiple cognitive processes, modalities and skills, many of which may be impaired in acquired brain injury. The aim of this thesis was to explore community travel and route learning in this population through a series of studies. The first study explored changes in community travel patterns and showed a reduction in all types of journeys, particularly unaccompanied and leisure trips. Disability and anxiety played some role in the reduction in travel but not as large a role as expected. The results of this study indicated that the reduction in community travel also impacted on quality of life. A virtual environment was developed and tested for use in the final two studies. This was followed by an investigation into the use of proximal and distal landmark strategies in route learning using the virtual environment. Findings suggested that people with traumatic brain injury have more difficulty using distal landmarks than proximal landmarks when learning a route. The final study built upon these results to develop a set of procedures to test whether it was possible to improve route learning in people with traumatic brain injury. Route learning skills were assessed using the virtual environment and then their naturally chosen strategy was supplemented with an additional one in order to improve performance.

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Dedication

This thesis is dedicated to Pat, Colin and Danny,

Bonnie and Eddie

& Winnie

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CHAPTER 1:

GENERAL OVERVIEW

1.1 Brief overview

Acquired brain injury (ABI) includes any non-degenerative brain injury that has occurred since birth (Wilson, 2008) and Headway (2009) reports 186,000 annual confirmed cases in the UK, 6% of these requiring rehabilitation. Patients with ABI may face a multitude of challenges including physical, behavioural, social, cognitive and emotional impairments. Wayfinding impairments are also common after ABI as wayfinding draws upon many cognitive domains that are associated with the anatomical location of injuries (Antonakos, 2004). The aim of this thesis is to focus on route learning; an aspect of wayfinding behaviour that has been successfully tested in the past using virtual reality (Brooks, McNeil, Rose, Greenwood, Attree & Leadbetter, 1999; Hurlebaus, Basten, Mallot & Wiener, 2008; Janzen, 2006; Lloyd, Persaud & Powell, 2009a; Lloyd, Riley & Powell, 2009b). The proposed studies in this thesis will build upon previous research in four specific areas; community travel and quality of life after ABI, the development of a virtual reality environment to explore route learning, proximal and distal landmark-based cues on a route learning task and, finally, the development of a set of procedures to test whether it is possible to improve route learning in people with traumatic brain injury. The way in which this thesis will attempt to address these issues is explained below.

1.2 Overview of the thesis

The first literature review in Chapter 2 introduces the topic of wayfinding and summarises the key terminology which will be used throughout the thesis. The key processes involved in everyday human navigation are explained, with particular emphasis on the two classic frames of spatial reference; egocentric and allocentric. These are discussed alongside their neuroanatomical correlates, particularly the hippocampus. The chapter then moves on to review the literature relating to a key component of this thesis; wayfinding in ABI. This literature base is formed of a small number of case studies on topographical disorientation and, although largely descriptive, the case studies begin to illustrate the nature of the real world wayfinding difficulties experienced by people with ABI and importantly show that it is indeed possible to improve wayfinding in this population. This then leads into the first empirical study in the thesis (Chapter 3) which consists of an exploration of the functional impact of everyday wayfinding difficulties after ABI.

Chapter 3 first describes a small number of qualitative studies which have begun to describe the potential barriers to travel for people with ABI, with particular reference to one of the most commonly reported barriers; anxiety. The theoretical underpinnings relating to why people may feel anxious about travel and particularly using public transport are discussed. A cross-sectional questionnaire-based study is conducted, exploring changes in the types of journeys made after ABI and whether disability and anxiety underpin these changes. Finally, the impact of the reduction in community travel on quality of life is explored. Recommendations are made for ways to address these findings in rehabilitation and increase community integration.

Chapter 4 presents an overview of the literature relating to the clinical relevance of using virtual reality in rehabilitation, as well as the practical advantages of using this medium in research and rehabilitation, such as providing more ecologically valid ways of exploring everyday behaviours like wayfinding. Current research into VR and wayfinding is then discussed, before exploring some of the key studies relating to route learning. The importance of developing more engaging ways of exploring everyday behaviours is highlighted, before leading on to Chapters 5 and 6, which describe the testing and development of a virtual environment with which to explore route learning.

Following the development of the virtual environment and testing the suitability of the controls in participants with ABI, the next experimental study is reported (Chapter 7). In this chapter, previous research into the use of different types of landmarks (proximal and distal) for wayfinding is discussed, together with the difficulties encountered by people with traumatic brain injury (TBI) in using distal strategies. The results of a study exploring the use of proximal and distal landmarks for route learning in people with TBI are reported and implications of these findings are discussed.

Chapter 8 builds upon the virtual reality route learning study and describes two case studies designed to explore whether people with TBI can supplement their naturally chosen wayfinding strategy (assessed using the virtual environment) with an additional strategy to improve everyday route learning skills. Finally Chapter 9 gives an overview summarising the findings reported in this thesis.

CHAPTER 2:

WAYFINDING AND ACQUIRED BRAIN INJURY:

DEFINING KEY CONCEPTS

2.1 Introduction

This chapter is a narrative account, defining the key concepts used in this thesis. These include wayfinding, spatial frames of reference and their neuroanatomical correlates, topographical disorientation and route learning.

2.2 Wayfinding and its component processes

Wayfinding is a broad term encompassing many aspects of spatial processing when we interact with our environment. Wayfinding can be defined as “the process of determining and following a path or route between an origin and a destination. It is a purposive, directed and motivated activity” (Golledge, 1999. p. 6). Successful wayfinding depends on the availability of internal strategies as well the ability to select an appropriate strategy (Dahmani, Ledoux, Boyer & Bohbot, 2012; Iaria, Petrides, Dagher, Pike & Bohbot, 2003). Making a simple journey may appear to require very little planning on behalf of the navigator but it, in fact, utilises multiple cognitive processes and skills (Algase, Son, Beel-Bates, Song, Yao et al., 2007), many of which may be impaired in ABI (Lemoncello, Sohlberg & Fickas, 2010a). Navigation has been defined as “making decisions about which way to go based on one's current goals, internal representations and perceptual cues" (Hartley, Maguire, Spiers & Burgess, 2003, p. 877). Given the similarity in the two concepts and a tendency in the literature to use the terms interchangeably, the same approach will be taken throughout this thesis.

Assuming the necessary motor skills or other means of moving through the environment are in place, a typical outdoor journey will first involve drawing on executive skills to formulate the goal to travel, initiate the actual journey and select an appropriate navigational strategy (Livingstone & Skelton, 2007). During the journey, working memory keeps the navigator on track and ensures the destination is kept in mind (Meilinger, Knauff & Bulthoff, 2008). Executive skills are also utilised here again to keep working memory engaged, to guard against distractions or perhaps prevent a diversion to another destination (Ciaramelli, 2008; Fish, Evans, Nimmo, Martin, Kersel et al., 2007). If it is a short, simple route, kinaesthetic information allows constant updating of our position in relation to the start point, ready for the return journey. However, on a longer route it is necessary to construct whole percepts of large scale objects in order to recognise them as landmarks and to encode them into long term memory for future reference.

Navigation of a familiar route may draw upon knowledge of a well-known sequence of landmarks or perhaps bring to mind a 'bird's eye' map of the area. The latter may be used in order to take a short cut or cope with a diversion (Cornell, Sorenson & Mio, 2003; Münzer, Zimmer, Schwalm, Baus & Aslan, 2006) Finally, the return journey draws upon long term memory of the sequence of landmarks or the cognitive map (see below) to remember the route. Here, it is also necessary to appreciate the altered spatial relationships that will exist between landmarks as they are viewed from a different direction. Given the multiple cognitive skills employed on a single journey, it is hardly surprising that learning and remembering a seemingly simple route can present a considerable challenge for people with ABI.

2.3 Spatial frames of reference for everyday wayfinding and their anatomical correlates

The literature on human and animal wayfinding studies refers to two general types of spatial reference frame which are central to our ability to find our way; egocentric and allocentric (see Galati, Michael, Mello, Greenauer & Avraamides, 2013 for a review). An egocentric frame of reference refers to the position of one's body, such as simply following a series of turns on a known route (often referred to as a route-based strategy or 'worm's eye' view). This frame of reference facilitates stimulus-response learning (Maguire, Burgess & O'Keefe, 1999) which may be intact after a brain injury (Packard & McGaugh, 1992) and may be a successful method for associating landmarks with directional information (Livingstone & Skelton, 2007). Alternatively, an allocentric reference frame uses a set of coordinates or environmental cues (and their relationship to each other), that are external or independent of the navigator (Harris, Wiener & Wolbers, 2012). This is often referred to as a survey strategy, developing a bird's eye view or cognitive mapping.

The cognitive map theory has been particularly influential in the field of human and animal wayfinding. Notably, the 2014 Nobel Peace Prize in Physiology or Medicine was awarded to John O'Keefe, May-Britt Moser and Edvard I. Moser for their “discoveries of cells that constitute a positioning system in the brain” (Sharlach, & Vence, 2014). The theory suggests that a cognitive map is a representation of allocentric space created in the hippocampus (O’Keefe & Nadel, 1979; Tolman, 1948). The role of the hippocampus and associated areas in allocentric memory is generally accepted, with evidence coming from research into ‘place’ and ‘grid’ cells (O’Keefe & Dostrovsky, 1971) and ‘head direction’ cells (Taube, Muller & Ranck, 1990).

Place cells were first recorded in the rat hippocampus and cells fired when the rat entered a specific area (place field), irrespective of its orientation (Muller & Bostock, 1994). They are linked to specific aspects of the environment (e.g. landmarks), so when these are moved, the location of the place cells moves correspondingly. They are therefore implicated in building a cognitive map. In contrast, head direction cells fire consistently in relation to a specific direction when the animal moves its head in that direction, regardless of the position of its body (i.e. they have a preferred firing direction) and they are thought to help to orient the animal in space (Taube, Muller & Ranck, 1990). Grid cells in the entorhinal cortex also facilitate navigation by helping to create a map of the environment that is independent of external cues and they interact with the place cells in the hippocampus, which are landmark dependent (Moser, Roudi, Witter, Kentros, Clifford et al., 2014). The application of these theories to human wayfinding is an exciting development, particularly for understanding the neuronal mechanisms involved in wayfinding impairments, such as those seen in dementia (Marquardt, 2011) or ABI (Barrash, 1998) but, until these mechanisms are better understood, their application to the rehabilitation of specific wayfinding impairments is somewhat limited.

Siegel and White (1975) hypothesised that acquiring knowledge about the environment occurs in stages beginning with the acquisition of sequential route knowledge and moving on to survey knowledge. More recent evidence suggests that allocentric and egocentric information is acquired in parallel from the beginning of a route (Burgess, 2008; Iglói, Zaoui, Berthoz & Rondi-ReigIgloi, 2009). Furthermore, we can also assemble both egocentric and allocentric representations of an environment based on kinaesthetic information alone (Lafon, Vidal & Berthoz, 2009), for example we can walk or reproduce a map of a path that we have only previously experienced whilst blindfolded. Some research presents convincing evidence that navigation involving allocentric space and the learning of allocentric spatial representations has been localised to the hippocampus, whereas processing of egocentric space and development of egocentric representations has been localised to the caudate nucleus (Bohbot, Iaria & Petrides, 2004, Iaria, Petrides, Dagher, Pike & Bohbot, 2003; Nadel & Hardt, 2004). A full review of the complex interplay between the roles of the hippocampus and the environment is beyond the scope of this thesis and lthough there is a general consensus that various aspects of spatial learning and memory are reliant upon the hippocampus and associated areas, this evidence does not yet present a clear model that provides practical suggestions for people with wayfinding impairments.

Irrespective of the role of the hippocampus, egocentric and allocentric strategies rely on external cues. However, moving from one place to another also uses internal cues as the spatial relationship changes with movement. This process is referred to as ‘spatial updating’ and involves ‘dead reckoning’ or ‘path integration’ i.e. keeping track of the general direction of travel in relation to one’s start point (Wiener, Berthoz & Wolbers, 2011). Early studies which suggested that damage to the right temporal lobe is associated with difficulty performing dead reckoning, also implicated the hippocampus in this ability (Worsley, Recce, Spiers, Marley, Polkey et al., 2001). Recent work suggests that grid cells in the entorhinal cortex support the process of dead reckoning by helping us to create an internal map that is independent of objects in the environment (Moser et al., 2014). The process of dead reckoning enables us to maintain an awareness of the direction and distance travelled from our start point through the continuous processing of kinaesthetic information from vestibular, proprioceptive and efferent motor neuron systems (Wallace, Choudhry & Martin, 2006). The ability to utilise this information is best illustrated from studies which show that participants who are congenitally blind can acquire allocentric and egocentric reference frames. However, allocentric reference frames are much more difficult to acquire in this way without visual cues than egocentric representations (Iachini, Ruggiero & Ruotolo, 2014; Ruggiero, Ruotolo & Iachini, 2012). This indicates that visual and motor cues are important during wayfinding but objects in the environment are also important in wayfinding.

Memory for objects or landmark location allows us to process the identity of the object (what) and the position of the object (where), and the combination of these two pieces of information (what + where binding) facilitates navigation (Ruggiero, Frassinetti, Iavarone & Iachini, 2014). In a recent comparison study of an individual with topographical disorientation (TD: see below) and a matched control group, Ruggiero et al. (2014) suggested that an individual with left lesions in the parahippocampal gyrus was able to recognise landmarks but had difficulty knowing their position. This was interpreted by the authors as a difficulty translating spatial information into egocentric reference frames i.e. they had difficulty processing ‘where’ and consequently this affected the binding of ‘what’ and ‘where’ components. This may prove important for people who are unable to derive directional information from landmarks and this is discussed further below.

2.4 Topographical disorientation

The broad term ‘topographical disorientation’ (TD) is often used in different ways in the literature and can refer to a combination of both agnosia and amnesia (see below), each of these in isolation (Brunsdon, Nickels & Coltheart, 2007), or even more generally as a set of “specific deficits that do not allow correct navigation and orientation” (Incoccia, Magnotti, Iaria, Piccardi & Guariglia, 2009, p. 293). Topographical or landmark agnosia is described as the inability to recognise landmarks or scenes (Aguirre & D’Esposito, 1999) and fMRI studies suggest that brain regions involved in prosopagnosia (posterior lingual and fusiform gyri) may also be important for landmark agnosia (Takahashi & Kawamura, 2002). In contrast, topographical amnesia refers to the inability to recall landmarks or scenes (McCarthy, Evans & Hodges, 1996). This suggests that there may be a dissociation between landmark recognition or perception and the ability to recall topographical information from memory (Brunsdon et al., 2007). This is supported by case reports of individuals with ABI who are not able to recognise familiar environments (e.g. their own house) but can draw and follow a map (Landis, Cummings, Benson & Palmer, 1986; Mendez & Cherrier, 2003). Alternatively there are some individuals who are able to recognise familiar landmarks but cannot use them to navigate (see Brunsdon et al., 2007 for a review).

2.5 Route learning

Route learning refers to the learning and remembering of a specified route or path and is a type of spatial behaviour which falls under the general, umbrella term of 'wayfinding'. When testing route learning, participants may be required to return to the beginning of a route and walk the same route again from beginning to end. This has been referred to as 'route retracing' (McCarthy et al., 1996). Alternatively, route retracing can refer to a scenario where a learned route is travelled in reverse from the end point back to the start (Lorenz, 1952; Wiener, Kmecova & de Condappa, 2012). Therefore, for the purpose of this thesis, and as suggested by Wiener et al. (2012), the term 'retrace' will be used to refer to the former (walking the route in reverse) and 'repeating' the route will refer to the latter (walking the same route again from the original start point). The repetition of a route, which is the experimental paradigm used in this thesis, is often conceptualised as a sequence of stimulus-response learning mechanisms (Trullier, Wiener, Berthoz & Meyer, 1997; Waller & Lippa, 2007) which may rely on the caudate nucleus (Hartley et al., 2003) and this is discussed further in Chapter 7.

Travelling along a learned route draws upon many cognitive domains associated with the anatomical location of injury (Livingstone & Skelton, 2007) and it is therefore, not surprising that route learning may be affected in people who have experienced a brain injury. In order to understand how to improve rehabilitation of wayfinding impairments, it is first necessary to investigate whether there is a change in real world travel patterns after a brain injury and the functional impact of these potential changes.

TRAVEL AND QUALITY OF LIFE AFTER ACQUIRED BRAIN INJURY

3.1 Introduction

The study described in this chapter explores whether travel patters change after acquired brain injury and whether this varies depending on the type of journeys people make. In keeping with the framework of the International Classification of Functioning, Disability and Health (World Health Organisation, 2001), travel related ‘activity limitation’ is measured using a new community travel questionnaire that has been designed specifically for this study. The study then focuses on factors associated with changes in community travel and, based on previous literature, particular emphasis is placed on whether anxiety makes a unique contribution to the change in travel, after accounting for other key factors that may impact on travel, such as problems with mobility. Finally, the perceived impact of this on ‘participation’ is measured using a quality of life questionnaire that includes satisfaction with various life roles, including involvement in the family, work, education and leisure.

The chapter begins with a narrative account of previous work in this area. It focusses briefly on the link between community travel, community integration and quality of life. It then focuses on the few descriptive papers that are particularly relevant to the current study, i.e. those that explore changes in community travel and the barriers to travel that have been identified by people with ABI. It will be apparent that anxiety features very strongly in this literature and so anxiety in people with ABI is then explored in greater detail. Subsequent to the literature review, and prior to describing the method for the main study, the development of a new measure of community travel is described.

3.1.1 Community travel, community integration and quality of life

National Clinical Guidelines published by the British Society of Rehabilitation Medicine (2003) provide a framework for ABI rehabilitation and they highlight the importance of "…improving activity and independence…" (p. 10), as well as "improving participation – and thus improving the quality of life for the patients and their families" (Foreword, p. 7). Satisfactory community participation or integration requires the opportunity for involvement in many aspects of daily life including work, leisure activities, independence in living situation and social relationships (Kim & Colantonio, 2010) and this naturally relies on the ability to travel for these purposes. In fact, an item related to community travel is included in the Community Integration Questionnaire (CIQ; Wilier, Ottenbacher & Coad, 1994), which is one of the most commonly used measures of community integration (Reistetter & Abreu, 2005). The actual item, "How often do you travel outside the home?", was found to have a strong relationship with the 'Social Integration' subscale of the CIQ in 312 people with TBI (Sander, Fuchs, High, Hall, Kreutzer et al., 1999), although it was originally situated in the 'Productive Activity' subscale. This is the only study to date, that has examined any aspect of the relationship between community travel and community integration in people with ABI.

Whilst there are no quantitative studies exploring factors predicting community travel in people with ABI (except for a small number of descriptive studies that are described in detail below (Section 3.1.2), several quantitative studies have explored factors related to community integration in people with TBI. A review of these by Reistetter and Abreu (2005) suggests that the main factors that predict community integration include disability, severity of injury, age, gender, education/work prior to injury and living arrangements. In the present study therefore, age, gender and education prior to injury will be included in a consideration of potential factors influencing community travel. However, given the main area of interest in the present study is the impact of anxiety on community travel after accounting for disability, this analysis will be carried out separately from the latter. All participants in the current study were community dwelling and so it was not possible to explore the predictive value of living arrangements. Only a small proportion of participants were engaged in work so statistical analysis of work status was untenable. Reistetter and Abreu (2005) note that summative measures of daily living skills provide stronger support for the link between disability and community integration than measures of individual components of activities of daily living. Therefore, the summative score of the Nottingham Extended Activities of Daily Living Scale (NEADL) will be used as a measure of the various types of disability that may occur after ABI in order to explore the impact of activity limitations on community travel.

With regard to community travel and quality of life, only two previous studies have explored this relationship and they have focused mainly on the component skills required for wayfinding, rather than travel patterns per se. Van der Ham, Kant, Postma and Visser-Meily (2013) explored the link between self-reported wayfinding skills and quality of life in people with mild stroke. Their wayfinding questionnaire included items relating to ability to estimate distance, ability to perform mental rotation (as required for map reading), sense of direction and anxiety about navigating alone. A question was also included that asked about the ease with which participants could return along a route that they had only travelled once. Each of the wayfinding subscales was then correlated with each subscale of the Stroke Specific Quality of Life Questionnaire (SSQoL: Williams, Weinberger, Harris, Clark & Biller, 1999). Results showed that all ability subscales of the wayfinding questionnaire were highly positively correlated with all subscales of the SSQoL, whereas the anxiety subscale was negatively correlated with SSQoL subscales. Furthermore, anxiety was negatively correlated with the single navigation item, highlighting the potential negative impact of anxiety on travel. The authors concluded that health-related quality of life benefits from good navigational skills, low anxiety related to navigation and they call for more research in this area. This study was limited in that it included people with only mild stroke who were living independently in the community and the psychometric properties of the wayfinding questionnaire were not reported. The present study will build on this work in a group of people with ABI who have a greater level of disability and it will also explore the relationship between anxiety and different types of community travel.

The only other study to explore the impact of community travel specifically, on quality of life, used a single item from the revised version of the CIQ (CIQ-2) as part of an exploration of community integration and quality of life in 162 people with TBI (Johnston, Goverover & Dijkers, 2005). In this version of the CIQ, the travel item was “Getting to places beyond walking distance independently” and this had a small but significant positive correlation with quality of life as measured using Diener, Robert, . Emmons, Larsen and Griffin’s (1985) Satisfaction with Life Scale. Other studies have explored community integration and quality of life in people with TBI but without any specific measure of travel or wayfinding. These studies generally support the notion that those who are less integrated into the community have a lower quality of life (see Reistetter & Abreu, 2005 for a review). This reduction in community integration has been shown to not only affect the individual, but also the family, with higher levels of psychological distress being reported by families whose relative is socially isolated (Winstanley, Simpson, Tate, & Myles, 2006). The studies described above therefore highlight the importance of addressing potential barriers to community travel during rehabilitation in order to prevent any negative impact on community integration and quality of life.

3.1.2 Descriptive studies of community travel after ABI

In addition to the quantitative studies described above, there are a small number of qualitative/descriptive studies that explore various aspects of community travel in people with ABI. One group of researchers (Sohlberg, Todis & Fickas, 2005) carried out a two-part study exploring navigation and community travel in individuals with long-standing cognitive impairments. In the first study, the researchers met with a small group of participants (N = 6) in one supported living facility over a period of 16 weeks. Participants were asked to report the trips they had made outside of the home each week and report where they had travelled each week. This was followed by a group discussion with other participants about their relative successes and any problems encountered during the trip.

The second study comprised six small focus groups attended by individuals with cognitive impairment of varying severity (low, moderate and high) living in a variety of settings (supported living facilities, living with family/spouse, living independently and in rural or urban areas). Care providers and public transport staff also participated in order to explore different perspectives on travel issues experienced by this group. The groups were generally not mixed (i.e. local transportation providers were in a separate group to individuals with mild cognitive impairment) and group numbers ranged from three to eight per focus group. The focus group transcripts were coded in two different ways; by participant profile to identify different speakers at the focus groups (e.g. individual with severe cognitive impairment, care worker) and by themes generated from the focus group (e.g. travel patterns, challenges encountered, strategies for coping with challenges). Two researchers generated the themes manually and coded segments were sorted by participant group and themes using the qualitative analysis software NVIVO.

The results of the first study showed that community travel was very restricted in this group. The number of independent trips outside the living facility ranged from two to three per week per person and the majority of these were short, routine and accompanied (e.g. using the specialised transport service with a member of staff to attend a medical appointment). Most of the independent trips were on foot and within close proximity of the living facility, and only two participants out of six used any form of transport independently (the bus). Participants expressed a wish to make more social and recreational trips such as going out to a restaurant, going to a shopping mall, visiting friends/family and travelling to other towns. In the second study, rehabilitation staff reported that the greatest challenge for participants was not related to difficulty with mobility, e.g. getting on and off the bus, but instead cognitive problems such as difficulty planning a trip, remembering the route, avoiding distractions or remaining aware of pedestrian safety. Anxiety was also reported to be a barrier to travel by both participants and staff.

Participants in the second study reported similar problems with community travel, regardless of their differing levels of cognitive impairment. The consequences of these problems were far-reaching, with incidents such as getting lost or forgetting where children had been dropped off being reported frequently and these often led to anxiety about travelling independently. Families also reported anxiety about their relative going out unaccompanied, giving rise to fewer opportunities to travel independently or to practise the skills necessary for community travel, which in itself could maintain anxiety in the person with the injury. This concept is further supported by the concept of the ‘influential gatekeeper’ described by Barnsley, McCluskey and Middleton (2012) during interviews with individuals (*n* = 19) who had very recently suffered a stroke (the mean time since injury was 58 days) and some of their partners (*n* = 8). Inclusion criteria were diagnosis of stroke, living in the community at the time of interview and actively attending specific rehabilitation services to increase community travel, including physiotherapy and/or occupational therapy sessions. The ‘influential gatekeeper’ was a theme generated from the interviews whereby people did not perform tasks (e.g. cross roads) or travel in the community because of the belief that therapists or families would not allow them to do so. The authors suggest that this type of monitoring or controlling of activities may not always be consciously imposed but that it may arise from feelings of anxiety about the individual’s capabilities. This is further supported by research into returning to driving after TBI, which suggests that families or significant others can sometimes ‘hold the keys to the car’ (Rapport, Bryer & Hanks, 2008, p. 927) and this can have negative consequences on levels of community integration (Rapport, Hanks & Bryer, 2006).

Travel strategies in the study by Sohlberg et al. (2005) were few and usually took the form of seeking support/assistance or simply not going out. Opportunity to travel (e.g. living near a bus route or having access to supported transport) did not affect the frequency of travel. Interestingly, one area in which groups differed based on level of cognitive impairment was acceptance, with those who were more cognitively impaired accepting their mobility limitations and feeling less frustrated by the reduction in community travel. This encapsulates a particular challenge after ABI, where individuals must find a balance between dealing with the consequences of their injury and psychologically adjusting to the situation. Supporting this adjustment is one of the key goals of brain injury rehabilitation (Schönberger, Ponsford, McKay, Wong, Spitz et al., 2014).

Overall, this study provides an insight into the community travel patterns of individuals with cognitive impairments after ABI but the sample size is small. The authors acknowledge that the small number of participants limits generalisability and that the increase in social contact between researchers and individuals in the first study, who normally have limited social contact in their everyday lives, may have affected results. The authors also report that it was difficult to collect enough data from participants with ABI, as those who did report difficulties with community travel simply did not leave the safety of their home due to anxiety, especially the fear of getting lost. In fact the theme of anxiety related to travel runs very strongly and consistently, through these two studies by Sohlberg, et al. (2005), suggesting that it is important to explore the role of anxiety as a potential barrier to community travel in a larger population. These studies were descriptive in nature and despite providing some detail regarding individual travel patterns in this small sample, questions still remain about trends in the wider population of people with ABI and underlying psychological mechanisms which may help us to understand or improve levels of community travel.

In a later study Sohlberg, Fickas, Lemoncello and Hung (2009) developed the ‘Activities of Community Transportation’ model to provide a framework for assessing and training community travel skills for people with cognitive impairments. The model is essentially a comprehensive task analysis, specifying the individual steps necessary to reach a destination using public transport (e.g. know your goal destination, plan a trip, leave the house on time etc). The model may have a practical application in travel training and may aid transport planners to improve services for people with cognitive impairments at different journey stages but it does not fully incorporate psychological factors, such as anxiety and how this may affect the individual at any stage of the journey. Interestingly, the authors report that the most challenging area for their participants was not using public transport itself (e.g. getting on and off the bus, pay fare, secure seat) but instead utilising cognitive skills such as planning a trip, remembering the route, avoiding distractions or remaining aware of pedestrian safety. However, the authors also report that it was difficult to collect enough data for participants with ABI, as those who did report wayfinding difficulties did not frequently travel outside their home due to anxiety, fear of getting lost or leaving their home where they felt safe. This study therefore indicates that in order to improve quality of life after a brain injury, it is necessary to explore how the most commonly reported barrier; anxiety, affects community travel patterns and to investigate ways to equip individuals with the necessary skills to reach a destination safely and independently, in order to increase community integration.

Another group of researchers used qualitative methods to explore the challenges faced by a small group of participants (*N* = 8) with cognitive problems causing functional limitations after a stroke (Risser, Iwarsson & Ståhl, 2012). Inclusion criteria stipulated that all participants used the bus, lived in ordinary housing (not supported living facilities) and were 18 to 32 months post-stroke. Cognitive impairments are not stated but all participants were recruited from the Swedish national register of stroke incidents via a local hospital. Participants took part in a semi-structured interview about their mobility, their perceptions of provisions made for people with mobility limitations and their thoughts and experiences of using public transport themselves. In the second part of the study, participants were accompanied by two researchers on a trip using public transport (the bus). Destinations included familiar places (e.g. the hospital) and less familiar places (e.g. new parts of the town, trips to the coast) but the number of places visited on each trip is not stated. During these trips the participants were recorded and encouraged to 'think aloud' and comment continuously on their experiences, whilst being observed by the researchers who also took notes. These trips were immediately followed up with an interview in which the participant's evaluation of the trip was discussed and associated thoughts/feeling with reference to specific events recalled along the way. Deductive data analysis was performed on the observation notes and interview transcripts by categorising information according to the author's 'Diamond model' (see Risser, 2000) of five key themes; individual characteristics (e.g. attitudes, habits); infrastructure (e.g. crossing roads); communication between road users; transport mode (experiences of different types of transport) and society/structures (how different groups are viewed by society).

All participants in the study reported a number of barriers to travel. Some of the barriers related to physical difficulties such as negotiating high pavements, maintaining balance on a moving vehicle, crossing busy roads to reach the bus stop, reading timetables, and getting on and off the bus. Anxiety related to different aspects of the journey was also reported amongst all participants and identified as a barrier to travel for some. Examples included worrying about whether the bus would stop, having to get off the bus quickly and being in crowded areas. Many participants also reported avoidant behaviour as a result of anxiety, or feelings of apprehension about how they might be viewed by others if they had difficulty on public transport. These included not being able to do things quickly enough; generally feeling as if they were in other people's way; feeling stressed when different tasks had to be co-ordinated; and being afraid that they could not cope by themselves. This last example is consistent with the findings of Sohlberg et al. (2005) in which the need for support to be accompanied on trips was also a key theme. In the present study therefore, a distinction will be made between journeys unaccompanied and accompanied, in order to allow a more fine grained exploration of community travel after ABI. The role of anxiety is again also featured here, highlighting its importance as a barrier to travelling. Participants also reported that their car was their preferred mode of transport before their injury. This evoked feelings of regret that they were no longer able to drive and some reported missing the freedom associated with driving.

The small sample size, focus on one particular type of brain injury, the older age group of the participants (60 – 79 years) and prevalence of physical disabilities may limit generalisability of these results to a wider population. The itinerary for the observational trip was suggested by the participants themselves based on personal interest. The examples provided by the authors include trips to the doctors, visits to familiar buildings, trips to new parts of town and visits to the seaside. Unfortunately, the actual destinations are not listed for each participant and so it is not clear whether they were required to select both familiar and unfamiliar destinations or both long and short trips, which could impact on the level of anxiety experienced. This is important because an individual may feel differently about making a routine trip to the doctors compared to a longer journey to the seaside for recreation. A strength of the study is that participants were observed performing everyday tasks in real settings. This provides an insight into real problems experienced when travelling, such as anxiety. However, as in the study by Sohlberg et al. (2005), participants reported a preference for travelling with someone else and indeed they were accompanied on the observation trips by two researchers. Therefore, it is possible that the reported problems and levels of anxiety may have been even more pronounced if they had been travelling alone. In addition, the interpretation of results via a pre-determined heuristic may limit the analysis somewhat, but, nonetheless, these results do provide a detailed account of the nature of the challenges faced by individuals after ABI and, again, highlight the role that anxiety can play, not only during travel, but also as a complete barrier to travel.

Another key theme was related to not wanting to “disgrace themselves in the presence of others” (Risser et al., 2012, p. 115) which prevented them from travelling alone. Participants reported that these feeling arose from tasks such as having difficulty buying tickets or forgetting when to push the button to request the bus stopped, which they felt makes them “look stupid” (p. 115). The authors suggest that this could be related to a feeling of powerlessness (Miller, 1995), which could lead to travel avoidance. The themes also highlight a number of travel related-threat appraisals as discussed below.

A further study by Logan, Dyas and Gladman (2004) explored the barriers to public transport use and the impact of a reduction in community travel on the individual. A series of semi-structured interviews was conducted with 24 participants with stroke (median of 10 months post-injury). Although the participants were chosen because they had recent experiences of using transport, all of the participants in the study agreed that getting out of the house was very important to them and 75% expressed a wish to go out more often. Barriers to travel included anxiety about accident or injury, feelings of embarrassment or a reduction in confidence associated with this anxiety, negative evaluation of the cost of using alternative transport such as taxis or scooters, environmental factors such as proximity to bus stops, access to transport services or bad weather. The authors suggest that the barriers to travel do not exist in isolation and instead are a complex interplay of individual physical, cognitive and environmental factors, all of which need to be addressed in order to increase community travel in this population.

A further small study by Rosenkvist, Risser, Iwarsson, Wendel and Stahl (2009), used qualitative methods in the form of interviews to explore the challenges faced by seven participants who, in contrast to the study by Logan et al. (2004), had stopped using public transport. All seven had been living independently for at least three months after stroke. Similar to the participants in the study by Sohlberg et al. (2005), most preferred to be accompanied on journeys by people they trusted and who could provide them with understanding and support. The majority of participants were unable to pinpoint specific reasons for the decision to stop using public transport or indeed verbalise a conscious decision to cease using transport services. Instead, they described their associated emotions at the thought of travelling. For example, one participant commented that she was "…afraid, anxious and worried at the very thought of crossing the street to get to the bus stop" (Rosenkvist et al., 2009, p. 74).

The authors here, describe a group of individuals who had ceased using public transport and this resulted in one of two personal adjustments; to change their environment or to change their attitude towards using public transport. The environmental change took the form of utilising different modes of transport, such as travelling with friends or using specialised transport services. The attitudinal change seemed to be to reduce the importance of public transport altogether e.g. one participant chose to avoid thinking about activities which were no longer manageable, in order to avoid feeling depressed and instead reported it "was better to be grateful for what she could do today than to think about activities that she could not perform" (Rosenkvist et al., 2009, p. 72). The authors suggest that this adaption occurs in order to reduce cognitive dissonance (Festinger, 1962). The cognitive dissonance model suggests that individuals become uncomfortable with the discrepancy between their actions and beliefs and seek to reconcile the two (Festinger, 1962). Although it seems plausible to interpret some participants' apparent lack of concerns about the decision to stop using public transport as an effort to reduce the dissonance between the thoughts of wanting to use public transport but not being able to do so, it is clear from some of the quotations provided that experiential avoidance (Hayes, Wilson, Gifford, Follette & Strosahl, 1996) was also a major factor in the initial decision. One participant described how she avoided thinking about activities she could not manage because it made her depressed, another cites "blurred anxiety about everything related to using buses and trains…." (Rosenkvsit et al, 2009, p. 74). Interestingly, a pre-interview questionnaire indicated participants had a number of physical limitations (e.g. difficulty bending, kneeling, and reaching) and this may have contributed to reasons for no longer using public transport, aside from other concerns. Participants described the complexity of managing aids (e.g. a walking frame), on public transport which made the task completely impractical for them. Thus, it is clear from this paper that, when exploring the cognitive and emotional aspects of community travel, it is important to ensure that functional independence and mobility are also accounted for and this will therefore be considered in the present study.

One important barrier to community travel only briefly touched upon above, is the requirement to cease driving. Liddle, Fleming, McKenna, Turpin, Whitelaw et al., (2012) carried out a qualitative study exploring adjustment to driving cessation in 15 people with TBI and their carers. Cessation of driving not only impacted on community travel but also seemed to impact on personal identity with driving being described as integral to 'normality' and return to pre-injury functioning. Several participants preferred to rely on lifts from family and friends as a substitute for driving, rather than using public transport. In fact, only three of the 15, reported using public transport regularly. Barriers to the use of public transport included poor availability and timetabling in rural areas, difficulties with physical access, difficulty planning the journey and the cost of taxis. For four of the participants, even though walking would have been a possible alternative, this was seen as stigmatising.

In summary, research to date has provided some insight into how community travel changes after ABI and what the barriers to travel might be. These include the impairments caused by brain injury e.g. cognitive problems leading to forgetting aspects of journeys or failure to initiate journeys (Risser et al., 2012; Sohlberg et al., 2005; Sohlberg et al., 2009), various activity limitations e.g. mobility problems, difficulty coping physically with public transport and difficulty reading timetables (Logan et al., 2004; Risser et al., 2012; Rosenkvist et al., 2009; Sohlberg et al., 2005), having to cease driving (Liddle et al., 2012), anxiety about travel including fear of embarrassment in pubic (Logan et al., 2004; Risser et al., 2012; Rosenkvist et al., 2009; Sohlberg et al., 2005) and even carer anxiety about the person with the brain injury travelling (Barnsley at al., 2012; Rapport et al., 2008). However, the studies often have a narrow focus e.g. people with stroke only, or those who do not use public transport at all. They also have small participant numbers and so the pattern of changes across different types of journey is not explored systematically. Therefore, in the present study, a more systematic exploration of changes in community travel will be carried out with a larger number of participants with various types of acquired brain injury. It will also consider the various types of journey that have been delineated in the studies by Sohlberg et al. (2005) i.e. routine, leisure, accompanied and unaccompanied. The Nottingham Extended Activities of Daily Living Scale (Nouri & Lincoln, 1987), incorporates questions relating to many of the participation restrictions listed above such as mobility problems, ceasing driving, managing public transport and reading. It will, therefore, be used to control for disability when exploring the unique impact of anxiety on travel.

3.1.3 Anxiety in people with acquired brain injury

Anxiety about community travel is a consistent theme running through several of the descriptive studies outlined above, all of which suggest that it can be a barrier to travel. (Logan et al. 2004; Risser et al., 2012; Rosenkvist et al., 2009; Sohlberg et al., 2005). It also features in one of the few quantitative studies described earlier (van der Ham, et al., 2013). Some participants who had stopped using public transport after their brain injury may even have, in the long term, chosen to adjust their own attitude towards community travel rather than experience the aversive emotional consequences that might accompany it (Rosenkvist et al., 2009). In fact, there is evidence that individuals who have experienced a brain injury may be at an increased risk of developing symptoms of anxiety compared to the general population, although reports show considerable variation (Bertisch, Long, Langenbahn, Rath, Diller et al., 2013; Hiott & Labbate, 2002; Kay, 1993; Moore, Terryberry-Spohr & Hope, 2006). It has been suggested that anxiety symptoms occur in up to 60% of individuals with TBI (Anson & Ponsford, 2006; Hibbard, Cantor, Charatz, Rosenthal, Ashman et al., 2002) and as many as 70% of individuals with an ABI (Moore et al., 2006) but empirical findings have been inconsistent. One problem is that it is difficult to accurately determine the prevalence of anxiety disorders because symptoms of the brain injury itself can be similar to symptoms of anxiety and thus the prevalence can be over or underestimated depending on the sensitivity and specificity of the measure used (Soo & Tate, 2007). Nevertheless, there is evidence that anxiety can be a strong predictor of functional status and psychosocial outcome (Draper, Ponsford & Schönberger, 2008).

One recent study that is relevant to the current study, is that of Bertisch et al. (2013) who examined the different roles of generalised anxiety and cognition on functional difficulties in 54 outpatient participants with ABI. Multiple regression analyses were conducted to explore the relationship between neuropsychological test results (Wechsler Adult Intelligence Scale III and Wechsler Wechsler Memory Scale III, Wechsler 2009), self-reported anxiety (Beck Anxiety Inventory, Beck & Epstein, 1988) and carer-assessed functional impairment. The latter was assessed using the Head Injury Family Interview Problem Checklist (HIFI PCL; Kay, Cavallo, Ezrachi & Vavagiakis, 1995). The PCL consists of 43 items relating to everyday functioning in three domains; cognitive, emotional and physical. Carers rate their answers on a scale of 1 – 7 ranging from *no problem* to a severe *problem* with the item in question. The results showed that anxiety predicted a significant amount of the variance in emotional and cognitive functioning as assessed by caregivers, but neuropsychological test scores did not. The authors suggest that these findings further support the role of anxiety as a potential predictor of functional outcome post ABI.

One limitation to the study is that no operational definition of ‘caregiver’ is provided and so it is not clear whether participants who did not have a relative as a caregiver were excluded. It is possible that individuals without designated caregivers may be less impaired and, therefore, the results of the study may be biased towards more impaired individuals, thus limiting generalisability of the findings. Overall, this study highlights the importance of examining the relationship between anxiety and activities of daily life, which could in turn impact on quality of life in individuals with ABI and their families/carers.

3.1.4 Anxiety-related coping

As touched upon above, one alternative theoretical model to cognitive dissonance which may be particularly relevant to feelings of anxiety and a reduction in travel, is the stress-appraisal-coping model (SAC; Lazarus & Folkman, 1984). Within this model it is suggested that the appraisal of a stressor influences the response to it and also influences whether a coping response will be employed. If situations are initially deemed threatening (a ‘primary appraisal’), then a coping response is chosen based upon their ‘secondary appraisal’. For example, in the study by Rosenkvist et al. (2009), the primary appraisal could be interpreted as the threat associated with using public transport (or travelling independently) and the secondary appraisal as whether one has the ability to cope with this. If the individual feels that they do not, then they may implement an avoidant strategy such as avoiding public transport. This type of avoidant coping has been demonstrated after a brain injury (Riley, Brennan & Powell, 2004) and has been associated with higher levels of depression and anxiety (Anson & Ponsford, 2006; Draper et al., 2008). If the situation is deemed as a threat, a problem-focused strategy (actively dealing with the problem e.g. seeking other modes of transport) or emotion focused strategy (dealing with the emotions without trying to change the situation e.g. avoidance) occurs (Lazarus, 1993). This theory has been used as a framework to explore outcome measures and avoidance after a brain injury (Anson & Ponsford, 2006; Godfrey, 1996; Rutterford & Wood, 2006) and may offer some insight into the way in which problems (or stressors) are appraised with a view to developing therapeutic approaches in rehabilitation.

One group of researchers has employed this framework in an investigation of anxiety-related avoidance in TBI (Riley et al., 2004). The authors developed two questionnaires relating to threat appraisals and avoidance for everyday situations, the Appraisal Threat Avoidance Questionnaire (ATAQ) and the Specific Activities and Avoidance Questionnaire (SAAQ). The results suggested that threat appraisals and subsequent avoidance occur relatively frequently in individuals with a TBI. All participants (*N* = 50) reported a minimum of one threat appraisal; 74% of participants reported at least 10 and 32% of people reported at least 10 threat appraisals that would lead to avoidance. A majority of participants (84%) reported reduced participation in at least one of the 25 activities listed, because of a loss of confidence. However, it is somewhat surprising in the light of the previous studies described above, which suggest that anxiety is an important barrier to community travel, that for the SAAQ item "using buses, trains and taxis" 88% reported carrying out this activity before their injury and of those, only 7% reported a reduction in this activity. This could be because participants assumed that this included both accompanied and unaccompanied journeys with the former being less likely to be affected by anxiety and therefore still as frequent. Thus, in the present study, in order to explore threat appraisals in the context of different types of community travel, including journeys accompanied and unaccompanied, a number of statements were generated and combined to form the community travel and anxiety questionnaire.

3.1.5 Aims of the study

Collectively, this narrative review suggests that although there are some small scale descriptive accounts of changes in community travel after ABI, there is no larger scale study exploring these changes systematically. This is therefore the first aim of the present study. The descriptive accounts and one of the quantitative studies suggests that anxiety may be one of the key barriers to community travel and so the present study focuses on anxiety specifically. Furthermore, anxiety, unlike demographic and injury related variables, can be addressed during rehabilitation. Given that previous studies also highlight various types of disability (e.g. mobility problems and difficulties remembering aspects of the journey) as a major barrier to community travel (e.g. Liddle et al., 2012; Risser et al., 2012; Sohlberg et al., 2005), disability is accounted for when exploring the unique impact of anxiety on community travel. However, it must be acknowledged that there are other potential factors that are not modifiable via rehabilitation that may influence travel, some of which have been highlighted in studies looking at predictors of community integration e.g. sex, age, education and time post-injury (Reistetter & Abreu, 2005). These are therefore explored separately from anxiety, which is the main focus of the present study. Finally, this study will explore the impact of change in community travel on participation by looking at its relationship with quality of life. Although one study has looked at the impact of community integration on quality of life, only two studies have explored the direct impact of wayfinding/community travel on quality of life (Johnston et al., 2005; van der Ham et al., 2013). Again, given the significant impact that disability arising from ABI may have on quality of life (Dijkers, 2004), disability will also be accounted for in the analysis.

3.1.6 Research Questions

This study will explore five specific research questions:

1. Do patterns of community travel change after acquired brain injury?
2. How do community travel patterns change after acquired brain injury?
3. Does anxiety contribute to the reduction in community travel over and above disability?
4. Do demographic and injury related factors contribute to the change in community travel after acquired brain injury?
5. Is frequency of community travel related to quality of life, after controlling for disability?

3.2 Development of the Community Travel and Anxiety questionnaire (CTA)

The items from the CTA will be generated using the studies from Sohlberg et al. (2005) and Sohlberg et al. (2009), as these studies had focused specifically on the identification of community travel patterns and the potential barriers to travel after ABI. The studies described above have explored community travel relating to specific groups of individuals and the inclusion criteria for these studies included participants who regularly travelled by bus (Risser at al., 2012), used public transport (Logan et al., 2004), those who had ceased driving (Liddle at al., 2012) or those who had stopped using any kind of public transport (Rosenkvist et al., 2009). These specific studies may not necessarily reflect the wider population of individuals with ABI. Furthermore, the descriptive account by Sohlberg et al. (2005) delineated the journeys made after ABI according to certain characteristics including accompanied versus unaccompanied, or within close proximity (involving mainly routine trips such as errands to the local shop) or further afield (mostly for recreational purposes such as visiting friends). There is no existing measure that explores travel patterns systematically in this way in people with ABI and yet it is clear from their accounts that different types of journey are affected in different ways.

Existing questionnaires tend to measure discrete components of wayfinding skills such as the cognitive components of spatial knowledge (Everyday Spatial Questionnaire; Eliot & Czarnolewski, 2007), sense of direction (Santa Barbara Sense of Direction Scale; Hegarty, Richardson, Montello, Lovelace & Ilavanil, 2002) and general wayfinding abilities such as creating a mental map (Livingstone & Skelton, 2007). Similarly, as described above (Section 3.1.1), van der Ham et al. (2013) designed a questionnaire that assessed some of the component skills required for wayfinding including retracing a route back, but they did not explore the different type of journeys that may be made. Although their anxiety subscale asked participants to rate their anxiety in different situations for example ‘in an unknown city’, ‘exiting a train, bus, or subway station’, it is clear from the work of Sohlberg et al. (2005) that this assumes a level of independence that participants with more severe brain injury simply may not have. Therefore, a new questionnaire was developed for use in this study, the Community Travel and Anxiety questionnaire (CTA), which included both a measure of the frequency of different types of travel and a measure of anxiety in the context of a journey that most participants would be able to relate to.

3.2.1 Item Generation

In order to generate items for the CTA, a focus group was carried out which included four healthcare professionals at a local NHS outpatient brain injury rehabilitation service (one physiotherapist, one occupational therapist, one clinical psychologist and one speech therapist) and feedback from reviewers helped to improve the questionnaire. A list of the types of journeys made for the travel subscale (12 items) and the things participants reported worrying about for the anxiety subscale (36 items) were extracted by the researcher from Sohlberg et al. (2005) and Sohlberg et al. (2009). These were presented to the group (see Appendix D) and participants were asked to read though the items and then asked the questions listed below.

- Do you clients have difficulties with everyday travel? If so, what kinds of difficulties do they have?
- Do you have a way of assessing or measuring this?
- How do these types of journeys on the list compare to the journeys made by your clients? Is there anything else you would add or remove?
- Are there any items on this list that overlap with each other or are duplicated?
- Is this a helpful way to think about the types of journeys made and are there any other types of journey that should be included?

- Are these the kinds of worries that you notice your clients have about community travel?
- Are there any other worries that would be useful to ask about?

The focus group noted that difficulties with travel did not form part of the client assessment and this was an issue that was brought up by individuals or families at later stages during rehabilitation. They agreed that this was an important area to explore further, as clients may return to everyday life without these issues being addressed during rehabilitation. The group agreed with the types of journeys made (alone and accompanied) and the reasons for travel (leisure and routine). The group agreed that clients felt very differently about these two types of trips and many placed a higher value on leisure activities. For example, a trip to the doctors or to the rehabilitation centre was viewed as a routine trip that had to be taken. Whereas, going out for other reasons, such as meeting up with friends was seen as something which was optional and sometimes more valued by individuals. Examples given for leisure trips included meeting friends or going out for a coffee. It was suggested that these examples were added to the questionnaire to clarify the difference between types of journeys. They also noted that leisure trips were particularly important and clients often expressed regret about the types of leisure/social trips they used to make but were no longer able to do.

The group suggested that it was not necessary to have separate questions for each transport option (e.g. travel by bus, car, taxi etc), as the type of trip usually defined the method of travel used. For example, clients were often encouraged to make short local trips which would not involve transport, such as going to a local shop. This would involve walking or using a wheelchair to travel a short distance. Whereas, longer trips (e.g. going on holiday or visiting friends in another part of the country) would inevitably involve some mode of transport. In addition, combining the transport options in most questions would also allow participants to answer the question by selecting the mode of transport which was relevant to them. The focus group agreed that 'walking' would be used in questions one and two of the questionnaire because it reflected an important type of journey but that the researcher would amend this accordingly for each participant when reading the questions aloud (e.g. go out using your wheelchair/mobility aid etc). It was suggested this was preferable over including a long list of options in each question (e.g. walk, use wheelchair, use walking stick, use a mobility aid). It was also agreed that the transport options in the later questions would be merged to allow participants to select the most appropriate mode of transport for them, so that they could answer as many questions as possible. This left eight remaining questions which were asked both pre and post-injury (eight pre-injury and eight post-injury).

When looking at the anxiety subscale, the group recommended that the question should be centred around the most common type of trip, so that most clients would have experience of this type of journey after their injury (e.g. a short, local trip) and could think about this when answering the question. It was suggested that this question would need to contain a balance between a journey that most participants may have made after their injury and one that would elicit feelings of anxiety if they were present. It was suggested that although making a longer journey alone may induce more anxiety, clients may have difficulty answering a question which related to a journey that they were very unlikely to make or have experience of making after their injury. The group also agreed that the anxiety question should relate to travelling unaccompanied, as accompanied travel was much less likely to contain any anxiety-related feelings for clients, particularly when travelling with family of friends who they trusted.

The group noted that a lot of the anxiety questions from Sohlberg et al. (2009) related specifically to bus travel and as some participants may not use buses, this may prevent them from answering the question at all. Therefore, 19 transport-specific questions were removed from the anxiety subscale in total, leaving 17 questions reaming (see Appendix D). The group also suggested three additional questions were added based on their own experiences of taking clients out of the centre and the types of worries that were often mentioned. These were added to the questionnaire (items 9-12 on the CTA, see Appendix E) .These included being worried about being in a crowd (item 10 of the CTA) and feeling self-conscious about people looking at them because of their injury (item 11 of the CTA). The group also suggested that tiredness and physical exhaustion was missing from the questionnaire and this was a very real concern for clients when travelling (item 12 of the CTA). After adding these three questions, the anxiety subscale comprised 20 questions in total. The final questionnaire was thus developed based on Sohlberg et al., 2005, Sohlberg et al., 2009, the focus group and consultation with my academic supervisor. After this process, it resulted in 26 items in total (eight for a component designed to explore changes in travel and 18 for a component exploring anxiety about different aspects of travel).

To be a useful measure of change in travel since injury, the response scale for the travel component would need to include a measure of both frequency and change. In order to accommodate all types of trips, the frequency scale would need to be appropriate for everything from daily errands to annual trips to other areas of the country. The following five–point Likert scale was therefore the most parsimonious solution: *never, less than one to two times a month, one to two times a month, one to two times a week* and *most days*. For the purpose of analysis each response was assigned a score between 0 and 4. It was felt that a within participants approach would be more appropriate in order to reduce the error that could arise from using a control group of different individuals (Wacholder, Silverman, McLaughlin & Mandel, 1992). Thus participants would need to rate each item for both pre and post-injury. Repeating each item would create a very long scale therefore, it was decided to ask participants to put an *X* for before the injury and *O* for after injury. A similar response scale is used in the Brain Injury Community Rehabilitation Outcome Scale (Powell, Beckers & Greenwood, 1998) which is a validated questionnaire comparing personal and social functioning pre and post-injury.

For the anxiety component of the CTA, it was also important to account for any premorbid anxiety that might be associated with aspects of travelling. Therefore, it was decided to ask “compared to before your injury how much would you worry about…”. It was also clear from the descriptive studies (e.g. Rosenkvist et al., 2009; Solberg et al., 2005) and confirmed during piloting of the measure (see above), that participants often avoided some types of journeys completely, especially longer trips alone and therefore, would not be able to answer a question about anxiety related to these. Therefore, given that most people would make (or have previous experience of making) a relatively routine journey, participants were asked about how much anxiety this would evoke when travelled unaccompanied as, in keeping with Sohlberg et al. (2005), unaccompanied trips were likely to result in the most anxiety. A five-point Likert response scale was therefore chosen: *a lot less, a little less, no difference, a little more* and *a lot more.*

A second focus group was then undertaken with three staff (one manager, one centre co-ordinator and one activities co-ordinator) and two clients who had experienced an ABI, at a local Headway group. Individuals were encouraged to trial the questionnaire and comment on content, phrasing, style, appearance and ease of use. As a result of this process, a further eight items that were deemed not relevant or overlapping and were removed from the anxiety subscale (see Appendix D). For example, the expense of a taxi was deemed specific to taxi users only and most participants had free travel on local transport or travelled with family, so the focus group suggested that the price of travel may not be relevant to many participants. Further items were removed which were specific to other modes of transport such as forgetting where the car was parked and reading map whilst driving. The group also suggested that the original letters *X* and *O* in the travel component were replaced with the letters *B* (before) and *A* (after) to make the questions easier for participants to understand and the font size was increased for participants with visual impairments. This reduced the time taken to complete the questionnaire by approximately five minutes and this was deemed more appropriate for people with a brain injury. This resulted in eight items in the travel component (eight before and eight after injury) and 12 items in the anxiety component. Subsequent to the last focus group, and as discussed and agreed with the first focus group, the travel section of the CTA was divided into two components based on the sub categories identified in Sohlberg et al. (2005) and Sohlberg et al. (2009), i.e. travel accompanied versus unaccompanied, and routine versus leisure trips. This meant however, that longer journeys would inevitably be classed as leisure because these would include day trips and holidays and this was agreed at the focus group. (Table 3.1 shows the source of each item). It should be noted that categories overlap (see Appendix E for the CTA questionnaire.

Finally, in order to capture participants' general views about their overall change in travel a single item was added at the beginning of the scale i.e. "Compared to before your injury, how often do you travel outside the home?". The response scale used was similar to that used in the anxiety component of the scale i.e. a lot less, a *little less, no difference, a little more* and *a lot more*. In order to capture other possible reasons for the change in travel other than anxiety, an open question was added at the end of the CTA asking participants to provide the main reasons for any change in their travel patterns.

Table 3.1. *Travel items for the CTA (generated from Sohlberg, 2005 and 2009)*

	Travel Question	Sub category
1.	Walk somewhere by yourself along a familiar route	Travel unaccompanied Routine
2.	Walk somewhere with someone else along a familiar route	Travel accompanied Routine
3.	Travel by public transport or car by yourself on a routine trip e.g. to the doctors	Travel unaccompanied Routine
4.	Travel by public transport or car with someone else on a routine trip e.g. to the doctors	Travel accompanied Routine
5.	Travel outside your home on your own to socialise or for leisure e.g. go to meet a friend, go to the gym, go to a coffee shop	Travel unaccompanied Leisure
6.	Travel outside your home with someone else to socialise or for leisure e.g. go to meet a friend, go to the gym, go to a coffee shop	Travel accompanied Leisure
7.	Travel outside your home on your own on a longer journey by car train or bus, e.g. to go and visit a friend or relative in another area of the country	Travel unaccompanied Leisure
8.	Travel outside your home with someone else on a longer journey by car, train, or bus, e.g. to go and visit a friend or relative in another area of the country	Travel accompanied Leisure

The final anxiety section contained 12 questions in total and Appendix D shows each item. Participants rate their level of anxiety for each item on a five-point Likert scale. For example, “Q1: Compared to before your injury, how much would you worry about forgetting where you are going?” Responses and corresponding scores were assigned as follows; 0 = *a lot less*, 1 = *a little less*, 2 = *no difference*, 3 = *a little more*, 4 = *a lot more*.

3.2.2 Method

3.2.2.1 Design

The study employed a cross-sectional design to explore the psychometric properties of the new questionnaire.

3.2.2.2 Participants

Seventy participants with an acquired brain injury took part in the study. All were attending day services at the West Midlands and Worcester branches of Headway (a UK-based brain injury charity). The inclusion criteria were a confirmed ABI which had occurred at least six months prior to beginning the study and ability to give informed consent. The exclusion criteria were very severe memory impairment, marked communication difficulty or poor insight which would make it difficult for participants to complete the questionnaire. Demographic information is provided in Table 3.2.

3.2.2.3 Procedure

Staff at the day centres were briefed about the study and the inclusion and exclusion criteria. They were given the opportunity to ask questions and given information leaflets to distribute to potential participants. The researcher defined ABI to the staff as any non-degenerative brain injury that had occurred since birth (Wilson, 2008). ABI was confirmed by key workers at the centres (from their client records) and the researcher also asked key workers to confirm whether participants were suitable for inclusion in the study based on the exclusion/inclusion criteria. This was based on the client records and on the judgement of key workers, who worked very closely with the clients. Staff then approached potential participants who met the inclusion criteria and gave them an information leaflet. Participants who were interested in taking part made direct contact with the researcher who was frequently at the centres or indicated to a staff member that they would like to speak to the researcher about the study. The researcher then arranged a time explain the study in further detail and give participants the opportunity to ask questions. All participants were given a minimum of 24 hours to consider whether to participate in the study. Once agreed, appointments were made with participants at their day centre to begin the study. At the beginning of the questionnaire session, participants read and signed the consent form (Appendix C) and then answered the demographic questions. During the questionnaire administration the researcher sat with each participant, read the questions aloud and marked down their answers. This was to ensure that participants fully understood the questions and allowed for the inclusion of people who were unable to write down their own answers and ensured that all participants experienced the same conditions.

3.2.2.4 Ethical Approval

Ethical approval was granted by the Birmingham, East, North and Solihull NHS Research Ethics Committee (see Appendix A).

3.2.3 Results

3.2.3.1 Demographic Data

A total of 70 participants took part in the study; 52 were male and 18 were female. Participants' ages ranged from 26 to 79 years (*M* = 51.3 years, *SD* = 14.3), the mean age at the time of injury was 37 years (*SD* = 15.5) and the mean time since injury was 13.5 years (*SD* = 11.5). Forty participants sustained a TBI, 18 had a stroke, six had an anoxic injury, four had a tumour and two participants had a viral infection. Self-reported post traumatic amnesia for individuals with TBI (*n* = 40) was < 5 minutes (*very mild*) *n* = 2, 5-60 minutes (*mild*) *n* = 5, 1 – 24 hours (*moderate*) *n* = 6, 1+ days (*severe*) *n* = 8, not known *n* = 19. Details of education can be found in Table 3.2 and ethnicity in Table 3.3 below.

Table 3.2 *Frequency data for level of education (*N *= 70)*

Level of Education	*n*
No qualifications	19
O'level, GCSE, NVQ	30
A/AS level, Advanced GNVQ	12
First degree	7
Higher degree (MA, MSc, PGCE, PhD)	2

Table 3.3 *Frequency data for ethnicity (N = 70)*

Ethnicity	*n*
White British	56
Black British	4
White Other	3
Asian	3
Chinese	2
Mixed ethnic background	1
Prefer not to answer	1

3.2.3.2 Preparation for analysis of the CTA

For all items of the travel component of the CTA except for question 1, each response on the Likert scale was converted to a score between 0 and 4 where 0 indicated *never* and 4 indicated *most days*. For question 1 of the CTA "Compared to before your injury, how often do you travel outside the home" a score of 0 was assigned to a *lot less* and 4 was assigned to *a lot more*. Similarly, for the anxiety component of the CTA a score of 0 was assigned to *a lot less* and 4 assigned to *a lot more*. All items were administered by the researcher and so there were no missing data.

Alpha levels were set at .05 throughout the thesis (Field, 2007). A Kolmogorov–Smirnov test showed that none of the total subscale scores of the travel component were normally distributed. Therefore, median, mode and range for each of these subscales is shown in Table 3.4 (the maximum possible total score for each subscale was 16). The data for Question 1 "Compared to before your injury, how often do you travel outside the home?" were also not normally distributed. The median score for this question was 1 (*a little less*) and the modal score was 0 (*a lot less*). The range was 0 to 4.

Similarly, the total score for the anxiety component was not normally distributed. The median score for the total anxiety component was 21, the modal score was 18 and the range was 10 to 31. The maximum possible total score for this component was 48. The mode and median scores for each item of the anxiety component of the CTA are shown in Table 3.5.

Table 3.4 *Descriptive information for each item of the travel component of the CTA (N = 70)*

Item	Pre injury		Post injury	
	Median	Mode	Median	Mode
Walk by yourself	4	4	2	0
Walk with someone	4	4	3	3
Travel by bus or car by yourself	4	4	1	0
Travel by bus or car with someone	3	4	3	3
Travel on your own to socialise/for leisure	4	4	0	0
Travel with someone to socialise/for leisure	3	3	3	3
Travel on your own on a longer journey	2	2	0	0
Travel with someone on a longer journey	2	3	1	1

Table 3.5: *Descriptive information for the anxiety component of the CTA (N = 70)*

Item	Median	Mode	Range	
Forgetting where you are going	2	2	0	4
Using public transport	2	2	0	4
Forgetting the way there	2	2	0	4
Forgetting the way back	2	2	1	4
Talking to people you do not know	2	2	0	4
Going past your destination without realising	2	2	0	4
The thought of injury or illness	2	2	0	4
Forgetting why you went there in the first place	2	2	0	4
Not having someone to ask for help	2	2	0	4
Being in a crowd	2	2	0	4
Getting fatigued or physically exhausted	2	2	0	4
People looking at you	2	2	0	4

Table 3.6: *Descriptive information for the total subscale scores of the travel component of the CTA (N = 70)*

Item	Median	Mode	Range	
Travel unaccompanied pre-injury	13	12	2	16
Travel unaccompanied post-injury	6	0	0	14
Travel accompanied pre-injury	11.5	13	0	16
Travel accompanied post-injury	9	9	0	13
Routine trips pre-injury	13.5	16	2	16
Routine trips post-injury	8	7	0	16
Leisure trips pre-injury	11	12	0	16
Leisure trips post-injury	4	3	0	12

3.2.3.3 Reliability

The CTA was explored for internal consistency; the reliability coefficients for the whole travel component of the scale pre-injury was α = .75 and for the whole scale post-injury was α =.65. Reliability coefficients for each of the subscales of the travel component can be found in Table 3.7. Although some of the subscales of the travel component returned a lower α than the .7 recommended by Pallant (2007, p.7) it was felt necessary to retain all items of the subscales to maintain the overall integrity of the scale e.g. the same number of unaccompanied versus accompanied items and routine versus leisure items.

The anxiety component was also subjected to reliability analysis and returned an internal reliability coefficient of α = .76. However, three items produced an item total-correlation of less than or equal to the recommended *r* =.30 (Pallant, 2007, p. 92), (see Table 3.8) and were thus excluded. This included 'using public transport'; interestingly, many participants reported that they did not feel anxious about this because they never used the bus or train. Once these items were excluded, the scale still returned α = .76 which is deemed acceptable (Pallant, 2007) and the nine-item scale was used for all subsequent analysis.

Table 3.7 *Internal reliability coefficients for the travel component of the CTA*

Subscale*	Cronbach's Alpha pre-injury	Cronbach's Alpha post-injury
Travel unaccompanied (4 items)	.58	.73
Travel accompanied (4 items)	.64	.45
Routine trips (4 items)	.47	.48
Leisure trips (4 items)	.67	.37
Total scale	.75	.65

*Note. *Some items appear in more than one subscale.*

Table 3.8 *Item total correlation for each item in the anxiety subscale of the CTA*

Subscale	Item total correlation
Forgetting where you are going	.49
Using public transport	.31
Forgetting the way there	.42
Forgetting the way back	.40
Talking to people you do not know	.47
Going past your destination without realising	.41
The thought of injury or illness	.28
Forgetting why you went there in the first place	.54
Not having someone to ask for help	.52
Being in a crowd	.41
Getting fatigued or physically exhausted	.14
People looking at you	.43

3.2.3.4 Test re-test reliability

Test-retest reliability was conducted by asking a sub-sample of 16 participants selected at random to complete the questionnaire at two different points in time (within 6-8 weeks of the original test) to check whether the results were stable over time. An intra-class correlation coefficient was calculated for each subscale of the travel component of the CTA (Table 3.9) and also for each item of the anxiety component of the CTA (Table 3.10).

Table 3.9: *Intra-class correlation coefficient and 95% confidence intervals between point 1 and 2 for the travel subscale of the CTA*

Subscale	1	2	3	4	5	6
Pre injury	.95*					
95% confidence	.98-.10					
Post injury		1.0*				
95% confidence		.99-1.0				
Travel unaccompanied			1.0*			
95% confidence			.99-1.0			
Travel accompanied				.99*		
95% confidence				.98-1.0		
Routine Trips					.99*	
95% confidence					.98-1.0	
Leisure Trips						1.0*
95% confidence						.99-1.0

Note. * *Correlation is significant at* $p < .05$

Table 3.10: *Intra-class correlation coefficient and 95% confidence intervals between point 1 and 2 for the each item of the anxiety subscale of the CTA (9 item questionnaire)*

Subscale	1	2	3	4	5	6	7	8	9
1 Forgetting where you are going	1.0*								
95% confidence	1.0-1.0								
2 Forgetting the way there		1.0*							
95% confidence		1.0-1.0							
3 Forgetting the way back			1.00*						
95% confidence			1.0-1.0						
4 Talking to people you do not know				.88*					
95% confidence				.69-.96					
5 Going past destination without realising					.92*				
95% confidence					.78-.97				
6 Forgetting why you went there						.92*			
95% confidence						.80-.97			
7 Not having someone to ask for help							1.0*		
95% confidence							1.0-1.0		
8 Being in a crowd								1.0*	
95% confidence								1.0-1.0	
9 People looking at you									.94*
95% confidence									1.0-1.0

*Note. *Correlation is significant at p <.05*

3.2.4 Discussion

In summary, a new scale was developed that measures the frequency of different types of travel (unaccompanied versus accompanied, routine versus leisure) before and after injury. Although some of the subscales of the travel component produced a somewhat lower reliability coefficient than is recommended, this was likely to be related to the small number of items in each subscale (Pallant, 2007, p. 7). Test-retest reliability also proved to be good at .80 and above (Cicchetti, 1994). The scale was therefore deemed suitable for use in the main study.

The new scale also measures anxiety related to travel. Two items of this component showed poor item-total correlations and so were removed, leaving nine of the original 12 items. The final nine item anxiety scale proved to be internally reliable and also showed good test-retest reliability and so was also deemed suitable for use in the main study below.

3.3 Travel and quality of life after acquired brain injury

3.3.1 Method

3.3.1.1 Design

The study employs a cross-sectional questionnaire design to explore community travel after acquired brain injury. Comparative methods will be used to explore differences between pre and post-injury travel. Multiple regression analysis will be used to explore factors associated with these changes in community travel with a particular focus on disability and anxiety. Regression analysis will be used to explore the impact of changes in community travel on quality of life after ABI.

3.3.1.2 Participants

Seventy participants with an acquired brain injury took part in the study. They were the same participants that were recruited for the development of the CTA as described above. Demographic details have therefore, been provided in Tables 3.2 and 3.3 (above).

For research Question 3 (Does anxiety contribute to the reduction in community travel over and above disability?), an a priori precision analysis was conducted using G*Power (Faul, Erdfelder, Lang & Buchner, 2007) to determine the sample size necessary for a multiple linear regression analysis with two predictor variables for the overall regression coefficient. Following Cohen's (1988) principles for effect size, where small = .02, moderate = .15, and large = .35; to detect a moderate effect with α set at .05 and an observed power of .80, a total sample size of 68 participants would be required. Therefore, 70 participants provided appropriate statistical power for this test.

3.3.1.3 Measures

Participants completed a set of demographic questions and three questionnaires. Two standardised measures were used and the third was designed specifically for use in this study (as described in section 3.2 above).

3.3.1.3.1 Nottingham Extended Activities of Daily Living Scale (NEADL)

A measure of disability was required in order to control for disability when exploring firstly, whether anxiety predicts the change in community travel and, secondly, whether the change in community travel predicts quality of life. The Nottingham Extended Activities of Daily Living questionnaire (Nouri & Lincoln, 1987) is a 22 item measure used to assess functional independence in four areas, mobility, kitchen activity, domestic tasks and leisure-based tasks. Participants choose from four response options to rate their own level of activity in the last 2-3 weeks. Responses and corresponding scores are assigned as follows; 0 = *task* not completed at all, 1 = *task completed with help*, 2 = *task completed on my own with difficulty*, 3 = *task completed completely on my own*. The questionnaire has good reliability (Nouri & Lincoln, 1987) and validity in stroke populations (Lincoln & Gladman, 1992). It has also been successfully used with traumatic (Lincoln & Radford, 2007) and other acquired brain injuries (Bateman, Culpan & Pickering, 2001). It was chosen because of its brevity and because most items focus on disability, e.g. walking outside, walking on uneven surfaces, managing money, and driving, rather than participation restriction. It therefore includes disability related barriers to travel such as those reported in previous descriptive accounts and summarised above (Section 3.1.2). Items also have the least overlap with the CTA and it is self-report rather than observer report and so is in keeping with other measures in the study.

3.3.1.3.2 Ferrans & Powers Quality of Life Index (QOLI)

The Quality of Life Index (QOLI; Stroke version) is a 36-item questionnaire used to assess subjective quality of life and the authors define this as a “person’s wellbeing that stems from satisfaction or dissatisfaction with areas of life that are important to him or her” (Ferrans & Powers, 1992, p. 29). The stroke version of the questionnaire was also developed for individuals with a brain injury (King, 1996) and is therefore deemed to be suitable for use in this study. Overall the questionnaire has good validity (Ferrans & Powers, 1985; Ferrans & Powers, 1992) and reliability, with a Cronbach’s alpha of α = .91 in a study with individuals who had a stroke (King, 1996) and α = .93 in a study with TBI participants (Brennan, 2002).

The QOLI is divided into four sub sections; family, social/economic, psychological/spiritual and health/functioning. Participants are asked to rate each of the 36 items for i) importance and ii) satisfaction. For example Q1 - part one: “How satisfied are you with your health?” and Q1- part two: “How important is your health to you?”. A 6-point Likert scale is used and scores range from 1 = *very dissatisfied/important* to 6 = *very satisfied/ important*. A separate score can be calculated for each of the four subscales, as well as a total quality of life score for all items. In accordance with the scoring instructions (Ferrans & Powers, 1992) satisfaction scores are recoded to centre the scale on 0 by subtracting 3.5 from each item. The recoded scores are multiplied by the raw importance scores to weight the responses and the weighted responses are added together. The final score is obtained by dividing the score by the number of questions answered by the participant and adding 15. This produces a range of scores from 0-30, the higher score indicating higher quality of life.

3.3.1.4 Procedure

Participants were recruited as outlined above. At the beginning of the questionnaire session, participants read and signed the consent form (Appendix C) and then answered the demographic questions. During the questionnaire administration the researcher sat with each participant, read the questions aloud and marked down their answers. This was to ensure that participants fully understood the questions and to allow for the inclusion of people who were unable to write down their own answers and to ensure that all participants experienced the same conditions. The order of the four questionnaires was counterbalanced to minimise order effects and these were completed in one session (1-2 hours with breaks).

3.3.1.5 Ethics Approval

Ethics approval was granted by the Birmingham, East, North and Solihull NHS Research Ethics Committee (see Appendix A).

3.3.2 Results

3.3.2.1 Preparation for analysis

Alpha levels were set at p =.05 throughout. No outliers were present and as the questionnaires had been administered by the researcher there were no missing data.

3.3.2.1.1 Research question 1: Do patterns of community travel change after acquired brain injury?

Question 1 of the CTA "Compared to before your injury, how often do you travel outside the home?" was used to explore this question and was subjected to a simple tabulation of the frequency of each category on the Likert scale.

3.3.2.1.2 Research question 2: How do community travel patterns change after acquired brain injury?

Total scores for each of the four travel subscales were first calculated for pre and post-injury separately. As described above, none of these subscale scores were normally distributed. Therefore, Wilcoxon Signed-ranks tests were used to compare pre and post-injury scores for each type of journey i.e. accompanied versus unaccompanied, routine versus leisure.

3.3.2.1.3 Research question 3: Does anxiety contribute to the reduction in community travel over and above disability?

Before exploring this question it was first necessary to ensure that the anxiety component of the CTA was a valid measure of travel related anxiety i.e. that anxiety regarding travel had changed compared to before the injury when assessed using the current measure. Each item on the anxiety scale was therefore subjected to a one-sample t test with the test value set at *no difference* i.e. a score of 2.

Next, a series of change in travel scores was first calculated by subtracting the total score pre injury from the total score post-injury for each of the subscales of the travel component of the CTA (change in travel unaccompanied, change in travel accompanied, change in routine trips and change in leisure trips). A negative score would therefore indicate a greater reduction in travel. Kolmogorov-Smirnov tests were carried out to explore whether these change scores differed from a normal distribution. This showed that two of the four subscales were not normally distributed i.e. change in travel unaccompanied and change in leisure trips. The total score of the NEADL and the total anxiety score of the CTA were also explored for normality. The total NEADL score did not differ significantly from a normal distribution but the total anxiety score did.

Five regression analyses were then performed with the total NEADL score entered in the first step (in order to control for travel related activity limitation), and the total anxiety score entered in the second step in order to establish the unique contribution of anxiety to change in travelling unaccompanied, change in travelling accompanied, change in routine trips, change in leisure trips and overall perceived change in travel as measured using Question 1 of the CTA "Compared to before your injury, how often do you travel outside the home?". The regression analyses were tested to see whether assumptions for regression were violated (as stated in Field, 2013). Tests to assess whether data met the assumption of collinearity (i.e. VIF > 10, tolerance <.01) indicated that multicollinearity was not a concern in any of the five regressions. The Durbin-Watson test also returned a value close to 2. None of the standardised residuals in any of the regressions was greater than 3, nor were there more than 5% of standardised residuals greater than 2 in any of the regressions, suggesting that the level of error within the models was acceptable (Field, 2013). Scatter plots of standardised predicted values against standardised residuals for each regression analysis suggested that heteroscedasticity was not likely to be a problem for three of the five regressions. However, for the change in unaccompanied travel and the change in leisure related travel, these plots suggested a level of heteroscedasticity that could create bias in the model (Field 2012).

3.3.2.1.4 Research Question 4: Do demographic and injury related factors contribute to the change in community travel after acquired brain injury?

Firstly, the data were explored to establish whether sex had any impact on Question 1 of the CTA and then on the four travel subscales. Given that a series of Kolmogorov Smirnov tests had shown that the dependent variables were not normally distributed a series of Mann-Whitney U tests were performed.

Next, in order to include educational achievement in a regression analysis with other demographic and injury related variables, this was recoded into two ‘dummy variables’ with 0 indicating no qualifications or qualifications below A’ level and 1 indicating A’ level and above. In preparation for the regression analysis, the variables age, time since injury and age at injury were explored for normality and then entered into five regression analyses as predictors of the Question 1 of the CTA (compared to before your injury how often do you travel outside of the home?) and change in each of the four types of travel. Kolmogorov-Smirnov tests indicated that time since injury and age at injury were not normally distributed. In each of the five regressions age at injury showed a tolerance of 5.774E-005 suggesting that it was highly collinear with the other variables in the regression and it was thus excluded from each analysis. Subsequent to this, none of the five regression analyses showed a VIF > 10, or tolerance <.01 indicating that multicollinearity was not a problem (Field, 2013). The Durbin-Watson test also returned a value close to 2. Similarly, none of the standardised residuals was greater than 3, nor was there more than 5% of standardised residuals greater than 2 in any of the regressions, suggesting that the level of error within the models was acceptable (Field, 2012). Scatter plots of standardised predicted values against standardised residuals for each regression analysis suggested that heteroscedasticity was not likely to be a problem.

3.3.2.1.5 Question 5: Is frequency of community travel related to quality of life, after controlling for disability?

The scores for Question 1 of the CTA "Compared to before your injury how often do you travel outside the home?", were first explored for normality as were the total quality of life score and the total score of the NEADL. The latter two were normally distributed. A hierarchical regression was then performed with the total NEADL score entered in the first step and Question 1 of the CTA entered in the second step. The VIF and tolerance levels suggested that multicollinearity was not a problem. None of the standardised residuals was greater than 3, nor was there more than 5% of standardised residuals greater than 2, suggesting that the level of error within the model was acceptable (Field, 2012). The Durbin-Watson test also returned a value close to 2. Similarly, a scatter plot of standardised predicted values against standardised residuals suggested that heteroscedasticity was not likely to be a problem.

3.3.2.2 Descriptive Statistics

The results of the Quality of Life Index and Nottingham Extended Activities of Daily Living questionnaires are presented in Tables 3.10 and 3.11 below. Although not compared statistically, the QOLI results are very similar to those of King (1996) who found an overall score of 22.9 in a sample of 86 participants with stroke (mean age 69 years and mean of 19.2 months post stroke); and also similar to Brennan (2002) who found a mean of 25.65 in a sample of people with TBI who were on average 8.6 years post-injury.

Table 3.11: *Descriptive information of the overall and subscale scores of the Quality of Life Index Questionnaire (N = 70)*

QOLI Subscales	*M*	*SD*	Minimum	Maximum
Health/Functioning	20.39	4.57	10.06	29.85
Social/Economic	20.85	4.43	8.57	30.00
Psychological/Spiritual	21.56	5.75	3.21	30.00
Family	23.35	5.33	10.50	30.00
Total Scale	21.14	4.09	9.81	29.57

Note. Higher score indicates better quality of life.

Table 3.12: *Descriptive information of the overall and subscale scores of the Nottingham Extended Activities of Daily Living (N = 70)*

NEADL Subscales	*M*	*SD*	Minimum	Maximum
Mobility	3.79	2.08	0	6.00
Kitchen Activity	3.83	1.46	0	5.00
Domestic Tasks	2.30	1.70	0	5.00
Leisure-based Tasks	2.63	1.47	0	6.00
TOTAL Scale	12.54	5.58	1.00	22.00

Note. Higher scores indicate less disability

3.3.2.2.1 Research Question 1: Do patterns of community travel change after acquired brain injury?

A simple tabulation of frequencies was carried out based on the first question of the CTA. This showed that 78% of the participants in the study reported a change in patterns of community travel after their brain injury. Most of these (72%) reported that they travelled *a lot less* or *a little less*. A smaller proportion (21%) reported *no difference* in their travel patterns and some participants (7%) reported that they travel *a little more* or *a lot more* since their injury.

3.3.2.2.2 Research Question 2: How do community travel patterns change after a brain injury?

Table 3.6 shows the median and mode for each of the subscales of the travel component of the CTA. With regard to routine trips, a Wilcoxon Signed-ranks test suggested that these reduced after injury (*Mdn* = 8) compared to before injury (*Mdn* = 13.5, $z = -5.85$, $p < .001$, $r = -.51$). Travel for leisure also significantly reduced after injury (*Mdn* = 11 pre versus *Mdn* = 4 post), $z = -6.84$, $p < .001$, $r = -.56$*). Further Wilcoxon Signed Ranks tests also showed that accompanied trips significantly reduced after injury (*Mdn* = 11.5 pre versus *Mdn* = 9 post), $z = -4.46$, $p < .001$, $r = -.38$) and that the amount of unaccompanied travel also significantly reduced after injury, (*Mdn* = 13 pre versus *Mdn* = 6 post), $z = -6.77$, $p < .001$, $r = -.57$. A Wilcoxon Signed-ranks test confirmed that the change in leisure trips (*Mdn* = -5) was greater than the change in routine trips (*Mdn* = -4), $z = -2.65$, $p = .009$, $r = -.23$). Similarly, a Wilcoxon Signed Ranks test confirmed that the change in unaccompanied trips (*Mdn*

Note: *r in the Wilcoxon Signed-ranks test indicates effect size (divide the test statistic by the square root of the number of observations; see Pallant, 2007). Effect sizes according to Cohen's 1988 principles are .1 = small, .3 = medium and .5 = large effect size.*

= -7) was greater than the change in accompanied trips (*Mdn* = -2), z = 5.43, p < .001, r = -.46), see Figures 3.1 and 3.2.

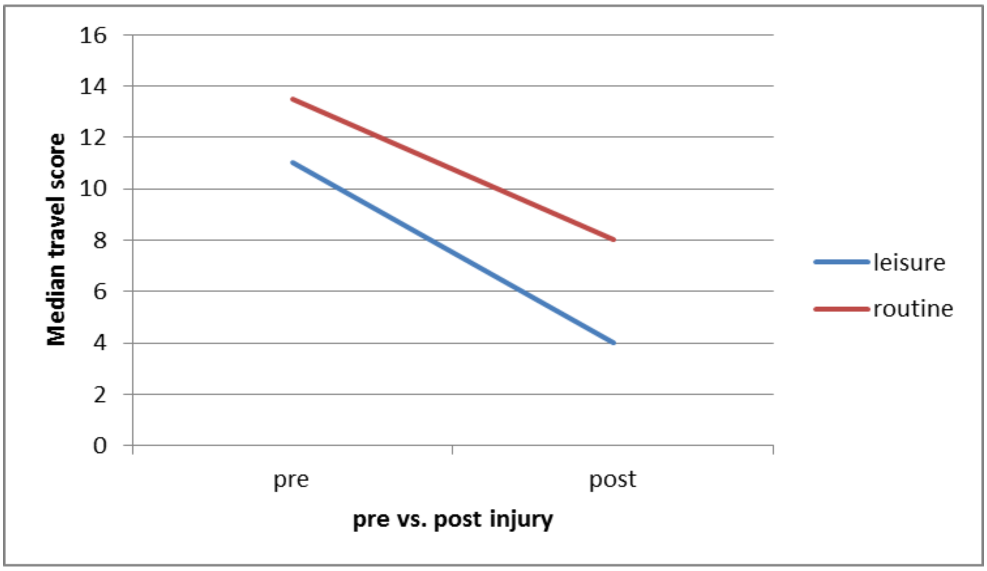

Figure 3.1: *Median pre and post-injury travel scores from the CTA for leisure and routine trips (N = 70)*

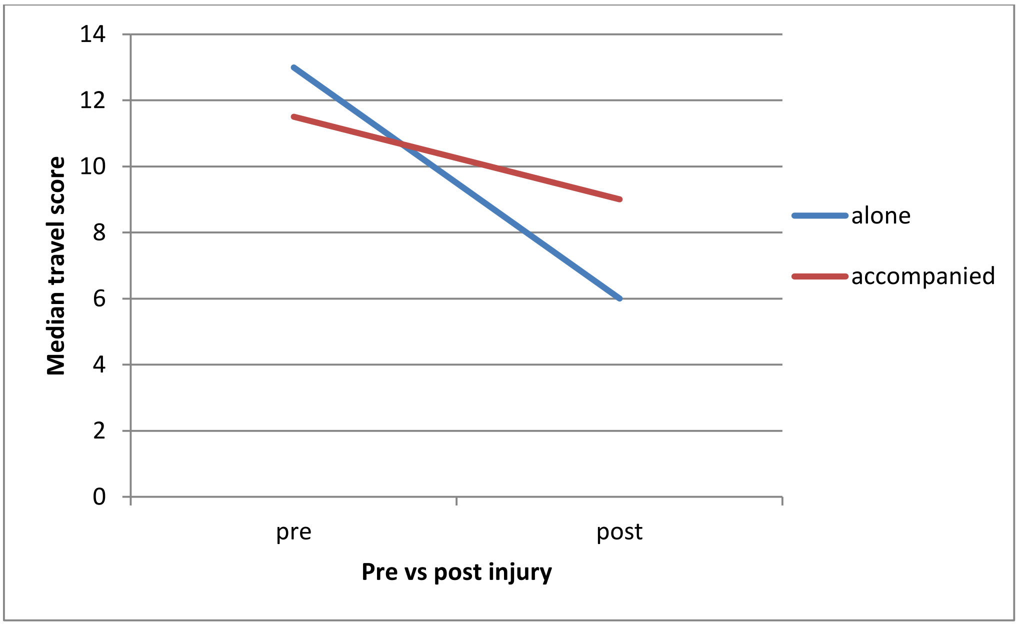

Figure 3.2: *Median pre and post-injury travel scores from the CTA for accompanied and unaccompanied trips (N = 70)*

3.3.2.2.3 Results of open question regarding change in travel

At the end of the questionnaire participants were asked to provide their main reasons for any change in travel. This was an open question in the CTA and was not answered by all participants, as it was only relevant to those who did experience an overall change in travel (*n* = 65). Each response was coded by the researcher based upon its meaning and then these were grouped into broader themes using an inductive approach. A second reviewer then inspected the data, checking whether each individual statement was consistent with the theme in which it had been placed by the first reviewer. There was no disagreement and none of the statements were moved.

Some participants offered multiple reasons and therefore, one person may appear in more than one category, but the overall reasons for the change in travel show that for those individuals who reported a reduction in travel, it was because they were no longer employed (*n* = 26); no longer able to drive (*n* = 24); felt anxious about travel, especially when travelling unaccompanied (*n* = 14); had health related/physical issues e.g. fatigue (*n* = 9); and reduced social activities/opportunities e.g. not in contact with friends (*n* = 6). Of the participants who reported an increase in travel (*n* = 4), one participant was attending an educational course to learn skills/return to employment, one participant went out more with their partner post-injury and two participants did not give a reason for the increase.

3.3.2.2.4 Does anxiety contribute to the reduction in community travel over and above disability?

Descriptive statistics for the anxiety component of the CTA are shown in Table 3.5. Although the modal score for each item was 2 (no difference) the frequency data for each item shown in Table 3.13 (see overleaf) suggests that when the responses *a little more* or *a lot more* worried are considered together, over a third of participants do have some concerns. There were two exceptions to this, “people looking at you” and “forgetting where you are going in the first place”. A one sample *t*-test comparing each item to a value of 2 (no difference), suggested that all items, except these two, were significantly different from this value. Thus suggesting that overall, the questionnaire was a valid measure of anxiety.

Table 3.13: *Frequency data for the anxiety component of the CTA*

Item	A lot less		A little less		No difference		A little more		A lot more	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Forgetting where you are going	3	4.3	3	4.3	36	51.4	20	28.6	8	11.4
Forgetting the way there	1	1.4	1	1.4	39	55.7	18	25.7	11	15.7
Forgetting the way back	0	0	1	1.4	45	64.3	16	22.9	8	11.4
Talking to people you do not know	2	2.9	3	4.3	38	54.3	17	24.3	10	14.3
Going past your destination without realising	1	1.4	1	1.4	42	60	14	20	12	17.1
Forgetting why you went there in the first place	3	4.3	4	5.7	49	70	8	11.4	6	8.6
Not having someone to ask for help	4	5.7	1	1.4	38	54.3	15	21.4	12	17.1
Being in a crowd	3	4.3	2	2.9	33	47.1	18	25.7	14	20
People looking at you	5	7.1	2	2.9	47	67.1	13	18.6	3	4.3

Table 3.14: *One-sample t-test to explore whether individual items of the anxiety component of the CTA are significantly different from 2 (i.e. no difference) (N = 70)*

Item	*t*(69)	*p*	95% CI *LL*	95% CI *UL*	Effect Size *r*	
Forgetting where you are going	3.56	<.001*	.17	.60	0.39	Medium
Forgetting the way there	5.33	<.001*	.33	.73	0.54	Large
Forgetting the way back	5.18	<.001*	.27	.61	0.52	Large
Talking to people you do not know	4.01	<.001*	.22	.64	0.43	Medium
Going past your destination without realising	4.93	<.001*	.30	.70	0.51	Large
Forgetting why you went there in the first place	1.45	.075	-.05	.34	0.17	Small
Not having someone to ask for help	3.63	<.001*	.19	.66	0.40	Medium
Being in a crowd	4.59	<.001*	.31	.78	0.48	Medium
People looking at you	1.02	.155	-.10	.30	0.12	Small

*Note. CI = confidence interval, LL = lower limit, UL = upper limit, *p<.05. Effect sizes Cohen (1988), r =.10 small effect, explaining 1% of the total variance; r =.30 medium effect explaining 9% of the total variance and r =.5 large effect explaining 25% of the total variance. Descriptive data for the anxiety subscale can be found in Table 3.5 and frequency data can be found in Table 3.13.*

As described above, in order to explore whether anxiety in itself is an important barrier to community travel i.e. to establish its unique contribution to the variance in change in travel, a series of five hierarchical regression analyses were carried out. In each regression the first step included the total NEADL score in order to account for any variance relating to disability. In the second step, the total score for the anxiety scale of the CTA was entered. Firstly, overall changes in travel in the community were explored. In this regression, the dependent variable was question 1 of the CTA "Compared to before your injury, how often do you travel outside the home?". The final model (Table 3.15) predicted 9% of the variance in the change in community travel ($F(2,67) = 4.41$, $p = .016$, R^2=.12, R^2_{Adjusted} =.09). Level of disability explained only 5% of the variance ($F(1,68) = 1.36$, $p = .248$, R^2=.02 R^2_{Adjusted} = .01) and anxiety explained an incremental 9.7% of the variance in travel scores above and beyond the variance accounted for by disability (R^2 change = .097, p =.009).

Table 3.15: *Summary of hierarchical regression analysis showing the predictors of the change in community travel based on Question 1 of the CTA (N = 70)*

	Variable	*B*	*SE*	*Beta (β)*	*t*	*p*
Step 1						
	Constant	.68	.30		2.25	.028
	NEADL total	.03	.02	.14	1.17	.248
Step 2						
	Constant	2.33	.67		3.46	.001
	NEADL total	.02	.02	.08	.68	.499
	Travel Anxiety	-.07	.03	-.32*	-2.71	.009

Note R^2_{Adjusted} *= .005 step 1 and* R^2_{Adjusted} *= .09 step 2, *p<.05*

Next, in order to carry out a more thorough exploration of the impact of anxiety on different types of travel, four further regressions were carried out including change in travel unaccompanied, accompanied, routine trips and leisure trips. For unaccompanied travel, the final model (Table 3.16) predicted 17.8% of the variance in the change in community travel ($F(2,67) = 8.45$, $p < .001$, R^2=.20, R^2_{Adjusted} =.18). Level of disability explained 14.7% of the variance ($F(1,68) = 12.89$, $p < .001$, R^2=.16 R^2_{Adjusted} = .15) and, although anxiety contributed 4.2% of unique variance to the model this did not represent a significant change (R^2 change = .04, p =.065).

Table 3.16: *Summary of hierarchical regression analysis showing the predictors of change in unaccompanied travel (N = 70)*

	Variable	*B*	*SE*	*Beta (β)*	*t*	*p*
Step 1						
	Constant	-11.89	1.44		-8.25	.00
	NEADL total	.38	.11	.40*	3.59	<.001
Step 2						
	Constant	-6.29	3.3		-1.91	.061
	NEADL total	.34	.11	.36*	3.23	.002
	Travel Anxiety	-.24	.13	-.21	-1.88	.065

Note R^2_{Adjusted} *= .15 step 1 and* R^2_{Adjusted} *= .18 step 2 *p <.05*

For change in accompanied travel and change in routine trips the regression analysis failed to return significant models (*F*(2,67)=. 21, *p* = .815 and *F*(2,67)=1.61, *p* = .208) respectively.

For change in leisure trips the final model (Table 3.17) predicted 8.7% of the variance in the change in community travel (*F*(2,67) = 4.31, *p* = .017, R^2=.11, R^2_{Adjusted} =.09). Level of disability explained 6.8% of the variance (*F*(1,68) = 6.06, *p* = .016, R^2=.08, R^2_{Adjusted} = .07), anxiety contributed 3.2% of unique variance to the model which did not represent a significant change (R^2 change = .03, *p* =.124).

Table 3.17: *Summary of hierarchical regression analysis showing the predictors of change in leisure trips (N = 70)*

	Variable	*B*	*SE*	*Beta (β)*	*t*	*p*
Step 1						
	Constant	-8.06	1.14		-7.09	<.001
	NEADL total	.20	.08	.29*	2.46	.016
Step 2						
	Constant	-4.37	2.62		-1.67	.100
	NEADL total	.18	.08	.25*	2.15	.035
	Travel Anxiety	-.16	.10	-.18	-1.56	.124

Note $R^2_{Adjusted} = .07$ *step 1 and* $R^2_{Adjusted} = .09$ *step 2* *$*p < .05$*

The regressions relating to unaccompanied travel and travel for leisure purposes showed contrasting results to Question 1 of the CTA i.e. disability was a significant predictor but anxiety was not (for Question 1 anxiety was a predictor but disability was not). Unfortunately, scatter plots of standardised predicted values against standardised residuals for these two regressions suggested that the assumption of homoscedasticity was violated (Field, 2012). Furthermore, in each case the partial regression scatter plots of each outcome variable against the predictor variables suggested that the relationship between anxiety and the two types of travel was a main source of heteroscedasticity. One possible reason for this was that the travel data, as suggested by Sohlberg et al. (2005), could be influenced by some participants not engaging in certain types of journey at all subsequent to their injury, thus reducing the spread in the data. Therefore, post-injury travel patterns were explored in greater detail, by examining the frequency of response for each post-injury travel item of the CTA. Table 3.18 shows that, as suspected, almost three quarters of participants reported that they never travel on longer journeys alone and over half never travel alone for leisure. Similarly, over a third never travel by bus or car alone.

Given the assumptions for these two regressions were violated, it was not possible to explore the relationship between all three variables together. The relationship between disability and each of the two types of travel was therefore explored individually. Anxiety was not subjected to the same analysis as the data could return a spurious correlation due to the problem described above. Significant correlations were found for disability and unaccompanied travel, r_s = .41 (p <.001) and for disability and travel for leisure purposes r_s = .31 (p =.008).

Table 3.18: *Frequency of post-injury travel based on individual items of the travel component of the CTA*

	Never		Less than 1 to 2 times a month		1 to 2 times a month		Weekly		Daily	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Walk by yourself post^	21	30	6	8.6	10	14.3	13	18.6	20	28.6
Walk with someone post	18	25.7	2	2.9	9	12.9	21	30	20	28.6
Travel by bus or car by yourself post^	31	44.3	5	7.1	6	8.6	14	20	14	20
Travel by bus or car with someone post	10	14.3	3	4.3	10	14.3	31	44.3	16	22.9
Travel on your own to socialise or for leisure post*^	38	54.3	3	4.3	8	11.4	17	24.3	4	5.7
Travel with someone to socialise or for leisure post*	12	17.1	6	8.6	11	15.7	34	48.6	7	10
Travel on your own on a longer journey post*^	52	74.3	11	15.7	5	7.1	2	2.9	0	0
Travel with someone on a longer journey post*	22	31.4	26	37.1	19	27.1	3	4.3	0	0

*Note. *leisure subscale ^unaccompanied journeys subscale*

3.3.2.2.5 Do demographic and injury related factors contribute to the change in community travel after acquired brain injury?

The impact of demographic and injury related variables was investigated next. In order to explore whether sex had a significant impact on travel patterns, differences between males and females on all dependent variables entered in the regressions above were explored. Given the data were not normally distributed, a series of Mann-Whitney U tests showed that there were no significant differences between males and females on Question 1 of the CTA Compared to before your injury how often do you travel outside of the home? (U = 397, p = .314), change in unaccompanied travel (U = 452, p = .834), change in accompanied travel (U = 413.5, p = .462), change in routine trips (U = 474, p = .936) or change in leisure trips (U = 548, p = .281).

In order to explore whether other demographic variables predicted change in travel, a series of five regressions were carried out using the same dependent variables as above with the following predictors for each: age, age at injury, time since injury and level of education (recoded as a dummy variable where 0=less than A' level and 1 = A' level of higher). Given there was no theoretical reason for entering predictors in any particular order, the 'enter' method was chosen. Two of the five regressions did not return a significant model i.e. Question 1 of the CTA "Compared to before your injury how often do you travel outside of the home?" F(3,66)=2.25, p = 0.091 and change in accompanied trips F(3,66)=2.02, p = .120 and change in leisure trips, F(3,66)=2.51, p = .070. In each of the five regressions age at injury showed a tolerance of 5.774E-005 suggesting that it was highly collinear with the other variables in the regression and it was thus excluded from each analysis.

The change in unaccompanied travel did return a significant model, three of the four predictors explained 7.2% of the variance (R^2_{Adjusted} = .07, F(3,66)=2.78, p = .048 but age was the only significantly predictor β =-.34, p=.007. This indicated that those who were older experienced a greater reduction in unaccompanied travel. The change in routine trips also returned a significant model with three of the four predictors explaining 12.8% of the variance (R^2_{Adjusted} = .13, F(3,66)=4.36, p =.007). Again, age was the only significant predictor β =-.39, p =.002 and suggested that those who were older experienced a greater reduction in routine travel.

Finally, change in leisure trips also returned a significant model with three of the four predictors explaining 13.3% of the variance (R^2_{Adjusted} = .13, F(3,66)=4.52, p =.006). On this occasion both age (β =-.31, p =.010) and level of education (β =-.27, p =.018) were significant predictors, thus suggesting that those who were older and had a higher level of educational attainment experienced a greater reduction in leisure trips.

3.3.2.2.6 Is frequency of community travel related to quality of life, after controlling for disability?

In order to explore the unique impact of the change in community travel on quality of life after accounting for disability, a hierarchical regression analysis was performed with the total NEADL score entered in the first step and Question 1 of the

CTA (Compared to before your injury how often do you travel outside of the home) entered in the second step.

Table 3.19: *Summary of hierarchical regression analysis for quality of life (N = 70)*

	Variable	*B*	*SE*	*Beta (β)*	*t*	*p*
Step 1						
	Constant	140.52	7.62		18.45	<.001
	NEADL total	1.36	.56	.28*	2.44	.017
Step 2						
	Constant	133.55	7.27		18.38	<.001
	NEADL total	1.09	.52	.23*	2.12	.038
	Q1 of the CTA	10.28	2.82	.39*	3.65	.001

Note. $R^2_{Adjusted}$ =.142 step 1 and $R^2_{Adjusted}$ =.239 step 2 *p <.05

The overall model (Table 3.19) predicted 21% of the variance in quality of life (F1,67) =10.17, p <.001, R^2=.0.23, R^2_{Adjusted} = .21), with disability accounting for 6.7% of the variance in quality of life (F1,68= 5.97, p = .017, R2=.08, R^2_{Adjusted} = .07) and the change in community travel contributing an additional 15.2%, making a significant contribution to the model (R^2_{Adjusted} =.15, p <.001). In summary, this suggests that, after accounting for disability, the change in community travel has a significant impact on quality of life.

3.4 Discussion

The present study investigated community travel patterns after ABI, the role of anxiety in community travel and the impact of change in community travel on quality of life. Potential demographic variables associated with changes in community travel were also explored. Results suggested that over two thirds of participants reported a general reduction in community travel. All types of community travel reduced, especially leisure trips and unaccompanied trips. When participants were asked a general question about how much they felt that travel outside of the home had changed, anxiety was a significant predictor. However, anxiety did not play a significant role in predicting the change in any specific type of journey. Demographic variables were also explored and being older was significantly associated with the reduction in three types of journey (unaccompanied, routine and leisure). The only other demographic variable that predicted a change in travel was educational achievement, with those who had a higher level of attainment showing a greater reduction in leisure trips. The reduction in community travel had a significant negative impact on quality of life after accounting for disability.

Participants in the present sample were predominantly white, British, male, just over half had experienced a TBI and they were an average of 13.5 years post-injury. Although not tested statistically, their profile on the NEADL suggests that relative to the participants in the study by Logan et al. (2004), they were experiencing a potentially higher level of disability. This demographic profile must be considered when interpreting results, as community travel and anxiety may differ in those who have had their injury more recently but unfortunately, there are no studies against which to make a comparison and the smaller scale studies discussed earlier were recruited from populations who also had mainly long-standing difficulties (Risser et al., 2012; Rosenkvist et al., 2012; Sohlberg et al., 2005). Although not tested statistically, self-reported quality of life in the current population was similar to that found by other authors in people with ABI (Brennan, 2002; King et al., 1996) and, as reported by Ferrans and Powers (1992) and cited in King et al. (1996), also similar to a random sample of 339 people in urban, suburban and rural communities.

Interestingly, during QOLI data collection, some participants spontaneously commented on their lack of friends but still continued to rate their answers as satisfactory on the scale. This may be because they had developed new friendships at Headway and, therefore, felt satisfied with these, or indeed that maintaining friendships was not an important factor in the subjective appraisal of their own quality of life.

In order to explore community travel, a new questionnaire was developed (the CTA). Unfortunately, some subscales showed lower than desired internal reliability but in order to maintain the integrity of the scale and explore all necessary types of travel both pre and post-injury, it was felt best to retain all items. The lower reliability coefficient could be due to the small number of items in each subscale (Pallant, 2007, p.7). The subscales with alpha levels that fell below the recommended 0.60 for newer scales (Nunnally, 1988), were pre and post-injury routine trips, post-injury leisure trips and post-injury accompanied trips, with trips unaccompanied just nearing the accepted level. These subscales and the anxiety component did however, show adequate test-retest reliability and the overall scale had good internal reliability.

3.4.1 Do patterns of community travel change after acquired brain injury?

Results of the present study suggest that when asked a general question about the frequency of post-injury travel compared to pre-injury, most people (72%) reported a general reduction in community travel. Far fewer (21%) reported no difference and 7% reported an increase in travel after their injury. Aside from a study focussing specifically on driving after TBI (Brooks & Hawley, 2005) involving 5,942 participants, this is the most extensive and expansive study of travel patterns, and therefore represents a new finding and a novel contribution to the field.

When asked to describe why the change occurred, participants reported most frequently that this was related to not returning to driving or employment. Given findings of a large study by the Department of Health (as cited in Brooks & Hawley, 2005) which suggested that only 16% of people with TBI are given specific expert advice about driving, current findings suggest a need to address this issue more carefully in order to maximise the potential for community travel.

The reason that some reported no change or an increase in travel was not specifically investigated. However, it is possible that there was a change in the purpose of journeys made, e.g. travelling regularly to college rather than work or travelling regularly to Headway rather than work. Furthermore, some participants at Headway take trips out with their support workers. It was clear from the themes identified in response to the open question regarding change in travel that participants who reported a reduction in travel, tended to report that external factors contributed to this, such as not being able to drive or having fewer friends to visit, with very few referring directly to internal factors such as anxiety. In contrast to Rosenkvist et al. (2009) who suggested that in the longer term people with ABI may offer a rationale that attempts to reduce the significance of community travel, responses to the question in this study about the reason for a change in travel seemed to openly acknowledge the barriers, albeit without explicit reference to a fear of travel.

3.4.2 How do community travel patterns change after acquired brain injury?

Results of the study suggested a change in the pattern of journeys made. Non-parametric analysis suggested that all types of journeys reduced after injury (accompanied, unaccompanied, routine and leisure). Furthermore, the reduction in leisure trips was greater than the reduction in routine trips and the reduction in unaccompanied trips was greater than the reduction in accompanied trips. This result is consistent with previous research by Sohlberg et al. (2005), who found that the majority of trips made after ABI were routine and accompanied. The present study extends their findings (which related to a small number of people) and suggest that this is an issue which needs to be addressed earlier on in the rehabilitation process, as the mean time since injury in the current sample was 13.5 years. In response to an open question, some participants reported an explicit anxiety about travelling unaccompanied, whilst others just said that they preferred to have someone with them during travel. One explanation for this finding may be the influential gatekeeper concept proposed by Barnsley et al. (2012), whereby the anxiety is not felt by the individual but rather the families or carers themselves. This anxiety may result in the individual not going out because they feel it is against their family’s wishes or they feel it might worry their family.

3.4.3 Does anxiety contribute to the change in community travel over and above disability?

When participants were asked how much they would worry about various aspects of travelling compared to before their injury, the modal response for each item of the anxiety component of the CTA was *no difference*. However, further analysis, suggested that the scores on all but two of the individual items ("forgetting why they were going somewhere in the first place" and "people looking at them") were significantly different from *no difference*. Furthermore, excluding these two items, over a third of participants reported either a little more or a lot more travel-related concerns e.g. being in a crowd, not having someone to ask for help and forgetting where they were going. This suggests that this component of the CTA was a valid measure of anxiety about travelling alone on a routine journey, although if this measure were to be used in future, it is recommended that two items are excluded.

Based upon a general question about the frequency of post-injury travel compared to pre-injury, regression analyses suggested that anxiety made a unique and significant contribution to the reduction in travel but disability did not. This is in keeping with several descriptive studies that highlight anxiety as a key barrier to travel (Logan et al. 2004; Risser et al., 2012; Rosenkvist et al., 2009; Sohlberg et al., 2005)

When exploring specific types of journey however, the picture was reversed; in those journeys that returned a significant regression model (unaccompanied journeys and journeys associated with leisure activities), anxiety was not a significant predictor, whereas a higher level of disability was associated with a greater reduction in travel. Unfortunately, no conclusions can be drawn from these regressions because they violated the assumption of homoscedasticity. A more detailed analysis of the post-injury travel patterns showed that a large proportion of participants never travelled on longer journeys alone and half never travelled alone for social or leisure purposes. This confirms the findings of Solberg et al. (2005) and Rosenkvist et al. (2009), suggesting that many participants simply avoid these types of journey.

Simple correlation analyses however, showed that those with greater disability were less likely to travel unaccompanied or to travel for leisure purposes. Although the relationship between anxiety, disability and these types of travel has not been established in the present study, future work might explore whether travelling accompanied by someone compensates for disability and thus, based upon the stress appraisal coping model (Lazarus & Folkman, 1984), this may mitigate any negative appraisals. As found by Riley et al. (2004), although threat appraisals may be common, they do not always lead to avoidance, implying that other ways of coping are available. Similarly, routine trips may be less impacted by disability and evoke fewer threat appraisals or less avoidance as people have learned to cope by over learning the route or they are known in the local community, perhaps from before the injury, and feel safer. This may also account for the finding above whereby routine trips to familiar places reduced proportionally less than leisure trips. Nevertheless, given that findings suggest quite a marked overall reduction in all kinds of trips, other factors aside from disability and anxiety might account for this and some of these are evident in the present qualitative findings, e.g. not having anywhere to go due to loss of contact with friends and family. As noted by Dijkers (2004) in a review of factors associated with quality of life in people with TBI, there is a substantial evidence base describing a reduction in friendships (Finset, Dyrnes, Krogstad & Berstad, 2005; Kersel, Marsh, Havill, & Sleigh, 2001; Reistetter & Abreu,

2005) due to diminished interpersonal skills and problems with self-control (Galski, Tompkins & Johnston, 1998; Snow, Douglas & Ponsford, 1997).

3.4.4 Do demographic and injury related factors contribute to the change in community travel after acquired brain injury?

When demographic variables were explored, those who were older experienced the greatest reduction in certain types of travel i.e. unaccompanied travel, routine travel and travel for leisure purposes. This is perhaps not surprising given that an association between older age and worse functional outcome has often been demonstrated after traumatic brain injury (e.g. Hukkelhoven, Steyerberg, Rampen, Farace, Habbemma et al., 2003) and also after stroke (Bagg, Pombo & Hopman, 2002). It has in the past been assumed that the ageing brain shows less plasticity although animal studies have started to challenge this notion suggesting the correct environment may facilitate greater recovery (Peterson, 2002). Hukkelhoven et al. (2003) note also, that this association is more likely to be explained by patient characteristics associated with age at the time of injury such as additional disabilities or comorbid conditions.

Interestingly, this study found that some of the reduction in travel associated with leisure was explained by level of education as well as age. Those who had a higher level of education experienced a greater reduction in travel associated with leisure. It is not clear why this should be the case although in a study of leisure activities after ABI, Wise, Mathews-Dalton, Dikmen, Temkin, Machamer et al. (2010) note that activities that are more likely to be abandoned after injury are those that demand both higher-level physical and cognitive adaptation. It is possible therefore, that the type of leisure activity before injury was more cognitively and physically demanding in those with higher educational attainment. This however, is unclear and remains an area for further research.

Sex did not have any impact on change in any kind of travel. Unfortunately, exploration of other factors such as premorbid living arrangements and type of employment prior to injury was beyond the scope of this thesis and is therefore a recommendation for future research.

3.4.5 Is frequency of community travel related to quality of life, after controlling for disability?

The results of the current study demonstrate that disability, together with self-reported overall change in community travel (Question 1 of the CTA) are significant predictors of quality of life. This is the first known study to demonstrate this direct link, the only previous study exploring self-reported wayfinding ability and quality of life (van der Ham et al., 2013) suggested a link with components of spatial navigation e.g. distance estimation and 'sense of direction'. Other previous studies have explored community integration and quality of life (e.g. Willemse-van Son et al., 2009). This study therefore, highlights the need to address problems of community travel during rehabilitation in order to promote community participation and improve satisfaction with quality of life.

3.4.6 Limitations

The questionnaire data in this study are based on self-report and may, therefore, be subject to some bias (Toglia & Kirk, 2000). Some caution should be exercised in the interpretation of pre-injury functioning which may have been subject to the ‘good old days’ bias (Iverson, Lange, Brooks & Rennison, 2010), resulting in a potential overestimation of pre-injury functioning and/or increased disappointment with one’s current situation (Gould & Ponsford, 2014). Although not tested significantly, given that self-reported quality of life was similar to a population without brain injury, the latter would seem unlikely.

Characteristics of the sample should also be considered, given that participants were recruited from local brain injury services. Access to such services may not be universal and this may have impacted on both travel opportunities (e.g. accessing the service required regular travel) and potentially, on quality of life (e.g. having a reason to travel, socialising with others at the day centre etc). A further limitation of the study related to the sample is that it was not possible to measure the impact of unemployment on travel, as none of the participants were in paid employment. Given that unemployment has been associated with lower quality of life after brain injury (Fraas et al., 2007), this may be an important consideration for future research.

The financial circumstances of participants were not measured in the current study, as these were not identified in the previous literature as a barrier to travel or endorsed by the focus group. It is interesting to note that when asked to explain reasons for any change in travel, no longer being in employment was mentioned by participants as a reason for the reduction in travel but financial restrictions was not identified here. However, financial circumstances may have contributed to community travel, and therefore, would be a further limitation of the study which could be addressed in future research.

Difficulties with insight could influence self-report (Toglia & Kirk, 2000) but it is hoped that this was minimised by the inclusion criteria i.e. key workers/staff were asked to confirm there were no problems with insight. The measures also showed adequate test re-test reliability and the researcher conducted all questionnaires personally, in order to facilitate completion and minimise any misunderstanding. However, a limitation of the current study is the question used in the anxiety subscale of the CTA. When completing this section, participants were asked to rate whether they felt there had been a change in the types of things that they worried about when making a short, familiar journey by themselves and a specific example was given (e.g. to the local shops). An alternative question to the one used may have been to ask participants to think about an accompanied trip. However, accompanied journeys may have been the least likely to elicit any feelings of anxiety, as previous research suggested that the majority of trips made by people with restricted community travel after ABI were routine and accompanied trips (Sohlberg et al, 2005). Another alternative may have been to ask about a trip to an unfamiliar place or to think about embarking on a longer journey. It was hoped that participants would be more likely to answer the question if it was regarding a journey which was familiar to them and one which they may be more likely to have recent experience of. Whereas a journey to an unfamiliar place or a longer journey may not be the type of trip which was made after their injury and therefore, may not have elicited any feelings of anxiety. It was hoped that the specific example used in the questionnaire would create a balance between allowing participants to think of a journey which they were familiar with (i.e. a short, familiar journey), one which may elicit some feelings of anxiety (i.e. travelling alone) but one that would not be too distressing for people who did experience very high levels of anxiety (e.g. a longer trip by themselves). However, this may have given rise to some error variance as there was no additional measure to confirm which type of journey or transport method each individual was thinking about. A further difficulty with this question is that some participants may not have reported anxiety because they could not imagine making this type of trip alone. This was addressed by selecting the type of journey which was most likely to have been made based on previous research (Sohlberg et al., 2005), as agreed with the focus groups but some participants may not have reported anxiety for this reason. Future research may benefit from using a different method to explore anxiety-related feelings about travel, such as making a trip on the bus in a virtual reality environment.

There was inevitably some overlap between some items on the mobility subsection of the NEADL and the CTA (e.g. using public transport). It was however, not possible to find a measure of disability without this issue, aside from those that focus on more basic skills e.g. the Barthel index (Wade & Collin, 1988) which would inevitably show a ceiling effect in the current population. This meant that some of the variance in travel may already have been accounted for by the NEADL rather than the CTA when predicting quality of life. The current results could therefore be subject to a type II error, slightly understating the importance of the link between community travel and quality of life.

Unfortunately, the internal reliability of some of the travel subscales of the CTA was not as high as recommended. This could, in part, be due to the small number of items in each subscale. In order to maintain the integrity of the scale and address the study questions, it was decided not to remove or substitute items. Fortunately, test-retest reliability was adequate. The lack of internal consistency could still, however, result in a type II error and may partly explain the lack of significant findings in terms of the relationship between disability and anxiety and certain specific types of travel. Furthermore, the latter relationship could not be tested in full as hoped, because the data violated assumptions for regression.

3.4.7 Recommendations and Clinical Implications

One of the central goals of the rehabilitation framework for ABI is to improve activity and promote participation, thus enhancing quality life (BSRM, 2003). The present study suggests that community travel is considerably reduced after ABI and this impacts on quality of life after a brain injury. It should therefore be a priority for rehabilitation. Based on the present study, a number of recommendations can be made for both future research and clinical practice.

It is important to address concerns about community travel as early as possible after injury so that avoidance does not become a barrier. During the questionnaire development therapists in the focus group reported that difficulties with wayfinding and independent travel are not identifiable via neuropsychological testing and may not become apparent until the individual attempts to return to everyday life, an issue also noted by (Koenig, 2012). This, together with the findings in this chapter and in the literature reviewed, might suggest the need for a ‘holistic’ assessment of barriers to travel after ABI. Ideally, this would begin with an assessment in a real life environment. However, if it is not yet possible for the client to engage in real world travel, virtual reality (VR) technologies offer the opportunity to test travel or address travel anxiety in a safe, controlled environment. It may also be possible to test ecologically valid solutions to real world travel problems in VR. This is therefore an area for further research and is discussed in detail in the next chapter.

If it is possible for the client to travel outside of the home, practice should include longer journeys for leisure purposes, as well as routine trips closer to the home. This should also include various modes of travel. Such real life exposure may provide therapists with insight into potential barriers to travel at an early stage, including travel-related anxiety. There should also be gradual exposure to travelling unaccompanied, with an emphasis on compensatory strategies to overcome any of the difficulties highlighted in the anxiety component of the CTA, such as not having anyone to ask for help or going past ones destination on the bus. Strategies to address such difficulties are described later this thesis (Chapter 8). Although anxiety did not play a significant role in predicting the change in any specific type of journey, there was a significant increase on most items of the anxiety component of the CTA. If necessary, the anxiety component of the CTA could be used to elicit potential concerns prior to travel practice and these concerns may be amenable to interventions such as cognitive behavioural therapy, which have reported beneficial effects in the treatment of anxiety after ABI (Waldron, Casserly & O'Sullivan, 2013)

Assessment should also include the potential to resume driving. Not returning to driving was reported as one of the most common reasons for the reduction in travel, indicating that driving was the primary mode of transport for a number of individuals before injury. This is also supported by other researchers in this field, some of whom also suggest that more information relating to return to driving should be supplied to people with ABI (Brooks & Hawley, 2005; Novack, Labbe, Grote, Carlson, Sherer et al., 2010). Logan et al. (2004) suggested that those who have been car drivers may identify specific barriers to using the bus e.g. difficulty understanding timetables, acquiring a bus pass and locating bus stops. Therefore, specific consideration should be given to equipping individuals with the skills that are needed to either return to driving or to use alternative forms of transport. This would facilitate more access to leisure activities which, according to the present findings, reduce the most.

Participants in the current study cited that they no longer had the same reasons to go out as they had before their injury, such as going to work and meeting friends. Assessment should therefore include reasons for pre-injury travel, with a focus on maintaining and promoting friendships in the early stages of rehabilitation so that people still have a reason to travel later on. One possibility might be the development of community integration/ support programmes e.g. buddy systems or mentors who may provide a reason for the individual to access the community. Meanwhile, future research could seek to clarify the extent to which loss of friendships impacts on community travel.

Assessment should also include the family's beliefs surrounding travel. As noted by Barnsley et al. (2012) in their gatekeeper hypothesis, families may inadvertently reinforce travel avoidance by reducing opportunities for unaccompanied travel, in order to reduce the anxiety for themselves and the individual. Education for caregivers about how anxiety develops and about the importance of travel and community integration (and the part the latter plays in protecting against caregiver stress; Fraas, Balz & Degrauw, 2007), would therefore, be an important adjunct to a rehabilitation programme.

Further research is needed to clarify the nature of the relationship between educational attainment and the reduction in travel related to leisure activities. Other potential barriers to travel that were not addressed in the present study, including the impact of changes in financial circumstances and access to public transport could also be addressed in future research.

In summary, as used in the present study, the CTA has begun to reveal the extent of travel-related activity limitation experienced by this population and shown that the main impact is on two aspects of travel (travelling unaccompanied and travelling for leisure purposes). It has also been shown, by measuring quality of life, that this reduction in travel impacts on satisfaction with community participation. It is therefore very important to explore potential barriers to community travel during rehabilitation and place a greater and earlier emphasis on this in order to maximise community participation and quality of life after brain injury.

CHAPTER 4

VIRTUAL REALITY IN REHABILITATION: AN OVERVIEW

4.1 Introduction

The past decade has seen the rapid progress of Virtual Reality (VR) technologies in response to a drive by the gaming industry to improve the graphics capability of the hardware and software available to develop virtual environments. A virtual environment (VE) can be defined as a “model of reality with which a human can interact, getting information… by ordinary human senses such as sight, sound and touch” (Blade, Padgett, Billinghurst & Lindeman, 2014, p. 33) and simulations can take a variety of forms ranging from fully immersive, multi-sensory environments on large projected, screens to those displayed on personal computers or hand-held devices. In contrast to fully immersive VR, desktop-based virtual environments are displayed via a computer screen and allow the user to fully interact with an environment without the use of specialist or costly equipment. This development has allowed researchers to utilise low cost, widely available technology which can be adapted to suit a wealth of applications and produce more intuitive, realistic and usable virtual environments which have potential to augment rehabilitation. This chapter will first discuss the problems with current methods of assessment in neuropsychological rehabilitation and the advantages of using virtual reality as a tool in brain injury rehabilitation, before summarising the current literature on route learning in virtual environments.

4.2 Assessment and rehabilitation of wayfinding in acquired brain injury

Rehabilitation of wayfinding difficulties in ABI is usually integrated into occupational therapy sessions, which take place towards the end of the outpatient rehabilitation process, as training cannot begin until the individual is able to walk (Koenig, 2012). The rehabilitation staff who took part in the focus group for the development of the questionnaire used in Chapter 3, reported that travel training is usually put in place at the specific request of the individual or the family. Training typically involves learning and remembering a specific route as part of an agreed and practical goal (e.g. learning to get to the bus stop or the route to work). However, if difficulties is no standardised way to assess real world wayfinding problems during initial neuropsychological testing, problems may not become apparent until returning to everyday life, when out-patient rehabilitation has ended and professional support is limited. Given that real world wayfinding is known to involve a number of cognitive skills which are often impaired after ABI (Algase et al., 2007), it is surprising that there is no standardised assessment of real world wayfinding used in clinical practice.

4.3 Ecological validity in assessments

Neuropsychological tests currently used in rehabilitation are designed to measure domain-specific cognitive abilities such as aspects of spatial memory and are substantiated by a wealth of scientific data supporting reliability and validity (Parsons, 2011). These tests are extremely useful for treatment and rehabilitation planning. However, advances in neuroimaging techniques have contributed to a shift in focus from testing for such purposes as identifying the location of injury, towards testing in order to make inferences about performance on everyday tasks (Spooner & Pachana, 2006). It is because of the latter that neuropsychological tests have been criticised for lacking ecological validity (Burgess, Alderman, Evans, Emslie & Wilson, 1998; Chaytor & Schmitter-Edgecombe, 2003) which has been defined as the "functional and predictive relationship between the patient's performance on a set of neuropsychological tests and the patient's behaviour in a variety of real world settings" (Sbordone & Long, 1996, p. 16). The results of research exploring the ecological validity of traditional neuropsychological tests has been varied. Some studies suggest that individuals who perform well on these tests may perform poorly in the real world (Gioia & Isquith, 2004) but others suggest that individuals who may achieve high scores on the test may have difficulty on the equivalent real world task (Stuss & Buckle, 1992). In addition, improvements in everyday life and functional independence are not necessarily reflected in improvements on the tests and there is some general agreement that neuropsychological tests should not be viewed as outcome measures as they assess impairment rather than functional adaptation (Wilson, 2008). Some patients may adopt different strategies in everyday situations, compared to those used in formal tests (Wilson & Exner, 2010) and it can also be difficult to capture motivation, which is not scored but may impact upon individual performance (Parsons, 2011).

In a review, Chaytor and Schmitter-Edgecombe (2003) report factors which may influence the ecological validity in traditional tests. These include whether clinicians, patients or carers are completing the outcome measures which are being reported and the approach being used for evaluation. The two evaluative approaches commonly used are veridicality and verisimilitude (Franzen & Wilhelm, 1996).

Veridicality refers to the predictive relationship between existing tests and measures of real world functioning, such as behavioural ratings, questionnaires or employment status (Spooner & Pachana, 2006). In contrast, verisimilitude refers to the similarity between the task used in the neuropsychological test and the skills used in everyday life. These tests are designed to reflect real world skills (e.g. the Rivermead Behavioural Memory Test; Wilson, Cockburn & Baddeley, 1985), rather than just to detect differences between neurologically intact individuals and those with ABI. This approach requires the development of new measures which require time investment and empirical testing before they can be used in practice. However it has been suggested that they demonstrate a stronger relationship with everyday life (Spooner & Pachana, 2006). Some authors have emphasised the importance of ensuring experimental control and establishing internal validity before assessing whether the tests can be used to draw conclusions or make inferences to real world tasks (Banaji & Crowder, 1989). Therefore, perhaps the most effective way to promote ecological validity in VR is to combine the scientific rigor of traditional neuropsychological tests in the development stages, with the creation of appropriate real world tasks which can be measured against current neuropsychological assessments.

4.4 Transfer of training and equivalence between the virtual and real world

The reasons outlined above suggest that there is a need to develop more ecologically valid methods of assessment and treatment in neuropsychological rehabilitation and virtual reality may offer a unique solution to this problem. Virtual reality offers the opportunity to explore wayfinding difficulties for individuals who may not otherwise be able to meet the physical demands of wayfinding tests in the real world. Virtual environments are intrinsically ecologically valid in that the stimuli used can be developed to reflect real world tasks that are more meaningful to the patient and may have greater generalisability to the real world (Rizzo, Schultheis, Kerns & Mateer, 2004). One way to measure the effectiveness of VR is to explore whether skills learned in VR transfer to the real world. 'Transfer of training' can be described as the ability of an individual to draw similarities between different tasks and to transfer learned behaviour from one task in VR to a task in the real world (Gick & Holyoak, 1983).

Transfer of training from VR to the real world is now well established in a number of fields such as surgery (Dawe, Pena, Windsor, Broeders, Cregan et al., 2014; Torkington, Smith, Rees & Darzi, 2001), physical rehabilitation (Yin, Sien & Ying, 2014) and training of practical or social skills for people with learning difficulties (see Aresti-Bartolome & Garcia-Zapirain, 2014 for a review). Earlier investigations in human navigation report poorer wayfinding performance in the virtual world when compared to the real world (Bailey & Witmer, 1994) but later studies have provided convincing evidence for the transfer from virtual to the real world in wayfinding tasks involving tasks such as mazes (Stanton, Wilson, Foreman & Duffy, 2000), simple indoor environments (Richardson, Montello & Hegarty, 1999; Ruddle, Payne & Jones, 1997), hospitals (Rose et al., 1998) complex buildings (Farrell, Arnold, Pettifer, Adams, Graham et al., 2003) and large scale outdoor environments (Darken & Banker, 1998).

Transfer of training studies are in contrast to those looking at ‘equivalence’, whereby task performance is not affected by the test environment i.e. performance is the same in both virtual and real worlds (Loomis, Lippa, Klatzky & Golledge, 2002). One study has begun to explore whether route learning performance is equivalent across real and virtual environments. Lloyd, Persaud and Powell (2009a) conducted a within-group study with neurologically intact participants (*N*=14). In the real world condition participants were driven around a real route by the researcher. After one learning trial, participants were returned to the start of the route and asked to repeat the route they had just seen by calling out directions just before each junction. The same procedure was used in the virtual condition except a different, equivalent route was learned in a virtual simulation of a different town. Whilst there was a good correlation between performance on both routes (VR and the real world driving route), it was not possible to see whether the virtual training transferred to a real world route, which is another important aspect of VR-based assessment and rehabilitation, as discussed above (Larson, Feigon, Gagliardo & Dvorkin, 2014). In both conditions, participants were ‘driven’ around the route by the experimenter and whilst this is useful for the purpose of the study (i.e. to explore equivalence), it means that we do not know whether the task demands of operating a controller for an individual with ABI would interfere with their route learning. This is particularly important if VR is to be used in brain injury rehabilitation.

4.5 Presence in the virtual world

One particular advantage of VR in rehabilitation and research is that it can elicit feelings of being transported to another place and this is often referred to as ‘presence’ (Slater & Usoh, 1993). There has been much debate in the literature regarding an exact definition of what constitutes presence (Bailey & Witmer, 1994; Stanney, 2002) but one of the most widely accepted definitions relates to …”the subjective experience of being in one place or environment, even when one is physically situated in another” (Slater, 1999, p. 2). Slater (1999) suggests that presence includes three aspects. The first is a sense of really ‘being there’ in the virtual environment. The second is the extent to which individuals respond as if they are in the VE, rather than the real world (e.g. moving their body in response to events occurring in the VE, such as trying look round corners). The third is described as the extent to which individuals remember their experience in the VE as having been in another place, rather than having been sat at a computer.

A greater sense of presence has been shown to facilitate task performance, increase transfer of training from the virtual to the real world and increase the efficacy of therapeutic applications (Minsky 1980). Conversely, a lower measure of presence has been associated with poorer engagement and task performance (Riva, Mantovani, Capideville, Preziosa, Morganti et al., 2007). Rose (1996) describes presence as one of the most “…vital characteristics…” (p. 5) of using VR in rehabilitation, where one has a real sense of being immersed in the environment, rather than being an operator sitting in a room, looking at a screen and therefore, it is important to consider feelings of presence when using virtual environments for research and rehabilitation.

A number of questionnaires have been developed to evaluate the different components of presence but longer questionnaires which require multiple answers may serve to distract the participant from the task and indeed disturb the very sense of presence they are trying to capture. It is also recommended that, where possible, the measure of presence should be captured while the participant is engaged in the VE, rather than after the task has ended and the feelings of presence may have diminished. Therefore it has been suggested that a more practical solution is to use a single question with which to gain a sense of the individual's feelings of being in the VE without distracting them from the task and these have been used successfully in VR studies to date (Bouchard, Robillard, St-jacques, Dumoulin, Patry et al., 2005; Bouchard, Dumoulin, Talbot, Ledoux, Phillips et al., 2012).

4.6 Virtual Reality in rehabilitation and research

Rose (1996) suggested that VR has the potential to increase interaction and stimulation through a process of environmental enrichment, which can increase stimulation for patients irrespective of reduced mobility, sensory or cognitive function. Nearly a decade on from these first suggestions, VR is now successfully being applied to a number of clinical and rehabilitation settings driven by scientific research. A non-exhaustive list of these includes panic and anxiety disorders (Botella & Villa, 2004), eating disorders (Riva, Bacchetta & Baruffi, 1999), post-traumatic stress disorder (Rothbaum, Hodges, Alarcon, Ready, Shahar et al., 1999), pain reduction (Hoffman, Patterson, Carrougher, & Gretchen, 2000) and social skills training (Parsons, Leonard & Mitchell, 2006). In the field of brain injury rehabilitation, the subject of the current thesis, other areas of interest include post-stroke motor rehabilitation (Jack, Boian, Merians, Tremaine, Burdea et al., 2001), assessment and rehabilitation of cognitive impairments (Rose, 1996), wayfinding and route learning

(Lloyd et al., 2009b). A discussion of all of these areas is beyond the scope of this thesis but the studies exploring route learning will be discussed in next section below, followed by a further review of the landmark-based navigation in VR in Chapter 7.

Virtual Reality also offers a number of practical advantages to researchers, such as the ability to manipulate stimuli in a controlled and experimental way, which would not be possible in the real world. For example, errorless learning, which has been found to be a beneficial technique in ABI (Evans & Wilson, 2000; Lloyd et al., 2009b), is much easier to control in VR, as systems can be programmed to prevent the user from being allowed to make errors. VR software is now more affordable, accessible and well supported by online communities offering resources and guidance for the development of VEs. In psychological research, VR can be used with neuroimaging technologies which provides a unique window through which researchers can explore the neurophysiological underpinnings of a multitude of real world-like scenarios which would not have been possible outside of the laboratory. These advances can enhance our understanding in a number of different areas which can feed into clinical rehabilitation practice and research. VR also enables multiple presentations of stimuli for learning purposes, which may not be possible in the real world, especially for those in the early stages of rehabilitation. This is particularly relevant to wayfinding research, where participants may not be physically capable of walking for long distances to practise a route.

Perhaps the one main disadvantage of VR for rehabilitation and in research is that of ‘cyber-sickness’, a type of motion sickness whereby people feel dizzy or uncomfortable using the VE (LaViola, 2000). However, this was more common in immersive VR where the entire visual field is covered (such as wearing a head-mounted display) and the real world is not visible. This is thought to be caused in part, by the mismatch between what is being presented visually and the sense of movement that is expected but not present (Strauss, 1995). Advances in software and hardware have gone some way to reduce feelings of cyber-sickness but, due to the nature of injuries of the participants in the current study, immersive VR was considered inappropriate. Non-immersive VR may however, be a helpful technique with which to investigate wayfinding ABI but it is important to create virtual environments and tasks which reflect real world scenarios, in order to encourage engagement with the task and increase the potential to develop a suitable rehabilitation tool (Rose, Brooks, Rizzo, Liebert & Rose, 2005).

4.7 Virtual reality route learning in acquired brain injury

The focus of the current thesis is wayfinding after a brain injury and existing case studies begin to offer an insight into the type of everyday wayfinding problems that are faced after ABI, but the lack of standardised assessment methods means comparisons between studies and recommendations for rehabilitation may not be valid (Wiener, Büchner & Hölscher, 2009). Therefore, it is important to clarify the exact nature of the wayfinding task in question and the present study will focus on one specific part of wayfinding, namely route learning. As previously described in the first chapter, route learning is a component part of wayfinding which involves learning and remembering a particular path from one place to another and is an essential skill for successful navigation. Route learning impairments are likely to be affected in ABI as route learning draws upon many cognitive domains associated with the anatomical location of injury (Livingstone & Skelton, 2007). However, it is not yet clear how to assist individuals with wayfinding difficulties or how to address them during rehabilitation. Next, this section will outline the previous work to date on VR route learning in ABI.

One of the first studies to use virtual reality to train route learning skills used errorless learning techniques to teach an amnesiac participant routes around a hospital was that of Brooks et al. (1999). Pre-training assessment showed the patient, was unable to learn and remember any real routes. The patient took part in a number of VR training sessions in which she was asked to learn routes around the hospital grounds in virtual simulations of the real world routes. Her first training sessions involved training on two of a possible 10 routes, for 15 minutes per day. This involved first watching the researcher perform the correct route in the VE, then the participant would repeat the route in the VE. Errorless learning techniques were employed where possible (i.e. if an incorrect turning was embarked upon, she was immediately corrected) and the routes were taught using a backwards chaining technique (i.e. after reaching each correct target, the participant was required to 'walk' backwards from the target, then move towards the target location again). After one week of training in the VE, the participant was tested on all 10 real world routes. The researcher who conducted the real world testing did not know which of the VR routes had been trained and this was one to control experimenter bias.

After three weeks' of VR training, the participant was able to complete the two trained routes in the real world. During the second phase of the study the participant was taught a new route in VR and another route in the real world. After two weeks of training using the same methods in each, she had learned the route which had been taught in VR but not the route taught in the real world. The authors suggest that in this case, VR offered a number of advantages which may explain why the participant was unable to learn the route in the real world training condition. The participant did not have to physically walk during the VR training and therefore, the routes were completed much more quickly in VR. This allowed for the participant to complete more laps of the route in the VR condition. The VE was also much more suitable for avoiding distractions which were present in the real world condition and also for performing the backwards chaining method. The authors noted that during the real world route training, other patients and staff were present in the busy environment, which made the backwards chaining method more difficult to complete without interruption. In a further study, the researchers were able to successfully train four more patients using the same VR methods (Rose, Attree, Brooks & Andrews, 2001). Overall the studies show a good degree of transfer of training from the virtual to the real world for route learning, which is important if these methods are to be used in rehabilitation. They also highlight some of the benefits of VR route learning, which may make VR a particularly suitable medium for route learning rehabilitation after ABI. These include the opportunity to repeat the route many more times than was possible in the real world in the same timeframe and to do so without the real world distractions. It also provided a way to incorporate learning techniques which may not always be possible in all real world route learning scenarios (e.g. backward chaining).

Another study exploring VR route learning in ABI, assessed an inverse type of transfer i.e. whether improvements on a verbally guided VR route learning task would generalise to other aspects of spatial processing (Kober, Wood, Hofer, Kreuzig, Kiefer et al., 2013). Participants with focal brain lesions (*n* =11) and a neurologically intact comparison group (*n* =11) completed a route finding task in VR. During a 20-minute training session, participants learned a route in VR and directional instructions were given verbally by the researcher (e.g. “We are approaching a crossroad now. We have to turn left here” p. 9). Participants were then asked to repeat the route in VR and also too call out the correct direction at each choice point along the route. Errors were immediately corrected by the researchers. Participants learned three routes per session and completed five training sessions in total. Route learning was assessed by calculating a weighted score between the number of turnings correctly recalled in the VE and the number of routes learned per training session. General spatial abilities were assessed before and after the task, using standardised tests of intelligence, orientation, visual short-term memory and implicit visuo-spatial memory (Kober et al., 2013).

The results demonstrated that both neurologically intact and brain injured participants increased their route learning performance over five training trials and route learning performance correlated with improvements on the standardised tests. The authors suggested that this type of VR route training can improve overall spatial abilities, and therefore, VR may be a useful tool in rehabilitation of spatial impairments. However, practice effects were not controlled for and without the addition of a control group who did not perform the VR route learning tasks, it is not possible to know whether the improvements on the tests of were due to practice effects, as a result of the additional route learning tasks or other reasons (e.g. confidence in their abilities). Interestingly, the authors also reported that participants with ABI scored significantly lower than the comparison participants on all of these tests but participants with ABI reported an increase in confidence and enjoyed the task more over time. This is consistent with reports from other studies of participants with cognitive impairments or older participants who at first resist the technology but ultimately adapt and engage with the task (Harris et al., 2012). This study highlights the fact that VR may indeed be a useful tool for rehabilitation but further research is needed to explore whether improvements on standardised tests transfer to improvements in the real world or indeed, whether improvements on these tests are necessary in order for individuals to experience meaningful improvements in everyday activities and increased participation (Wilson, 2008).

One study which has explored the equivalence between virtual and real world route learning in participants with TBI was conducted by Sorita, N'kaoua, Bernard, Larrue, Florian et al. (2012). The authors used 3D modelling software to create a VE, which was as close to the real world as possible but they chose not to include all aspects of the scene (e.g. some landmarks, road signs, moving people), stating that they hoped this would allow participants to focus on the spatial components of the environment. Participants (*N*=27) were divided in two groups and one group learned a 12-turn route in the VE, the other group learned the same route in the real world. In the VR route learning condition participants first watched the researcher perform the route and then repeated the route, completing three laps of the route before a single test trial. Errors were corrected by the researcher. The route was then repeated 1-2 days later, to test delayed route memory. After the route learning trials participants completed a sketch mapping test (draw a sketch map of the route and one point was awarded for each segment properly oriented to the left/ right/straight on, independent of the chronological organisation of the route), a multiple choice map recognition test (participants had to pick out the correct route from the main study on an aerial map, three of the routes were foils) and a scene arrangement test (participants had to arrange 12 pictures of junctions along the route in the order in which they were encountered). The procedures were the same for each condition but in the real world, the participants followed the researcher on the first learning lap of the route. In addition, participants in the real world walked along the pavements whereas participants in the VE were allowed to walk freely across the pavement and roads. This was to compensate for difficulties operating the controller, which might have interfered with the route learning task.

The authors reported that there was no significant difference between the real and VR route learning conditions on immediate route recall, delayed route recall, route recognition or the sketch mapping task but participants in the real world scored significantly higher on the scene arrangement test. The reasons for this difference may be due to differences between the virtual and real worlds in this experiment. Figure 4.1 below, is an example of the same scene in the virtual environment and the real world. Differences can be seen across the pictures (e.g. the VE does not contain street signs, pedestrian crossing markings, parked cars, the rooftops and chimneys on the left hand side of the picture are not visible etc.) and it is possible that these differences may have affected the scene arrangement test. It is not possible to know which strategies, if any, were employed during route learning but if landmark-based strategies were employed, then the real world may have offered more clues to help with the scene arrangement test. For example, the route may have been learned by using a series of stimulus-response turnings (Trullier at al., 2007) associated with salient aspects of the scene (i.e. turn right at the red sign, after the red sign, turn left at the road crossing) or using landmarks as beacons (Chan et al., 2012), which indicated the heading direction (i.e. first head for the red sign, then head for the road crossing). The virtual environment did not include as many landmarks, so this may have disadvantaged participants who may have used these to develop knowledge of the chronological order of the route.

It is also not possible to know whether participants had more difficulty arranging the scenes in chronological order in the VE because this temporal information had not been learned or remembered, or whether participants simply did not recognise the pictures of the VE from the perspective in the photograph. Participants in the VE were able to walk freely in the road and across the pavements. Therefore, the pictures they were shown in the VR scene arrangement test may not have matched their own representation of the scene (Mallot & Gilner, 2000), particularly if they had approached the junction from a different angle (e.g. from the other side of the road). In contrast, all participants in the real world condition walked along the pavement and therefore, may have had a more consistent approach to each junction, so that the pictures they saw matched their own representation of the scene.

a)

b)

Figure 4.1: *Pictures of the real (a) and virtual (b) routes taken from Sorita et al. (2012, p. 4)*

This study suggests that route learning performance may be equivalent across virtual and real worlds but that there may be some information gained in the real world that is not available in the virtual one. An alternative explanation for the differing results in the scene arrangement test between conditions is that some visual or movement cues which were available in the real world were not available in the virtual environment. For example, studies have shown that some neurons in the hippocampus may respond differently to passive head turns in VR, when compared to the real world (Shinder, & Taube, 2014; Taube, Valerio & Yoder, 2013) and some important vestibular cues which influence the firing of hippocampal cells during spatial processing, may not be fully activated during stationary navigation (Aghajan, Acharya, Moore, Cushman, Vuong et al., 2014; Taube, Valerio & Yoder, 2013). Overall, it is important to consider that despite advances in technology, there may still be some elements of real world route learning that are not fully captured in VR but the findings of this small study are encouraging for the equivalence across real and virtual environments on route learning tasks after a brain injury.

In summary, virtual reality offers a number of advantages for both research and for rehabilitation. It allows for the repeated presentation of material in a standardised and controlled way. It has the potential to facilitate learning techniques which may be more suitable for people with ABI (e.g. errorless leaning, backwards chaining) but which may not always be practical or free from other distractions in the real world (Brooks et al., 1999). Virtual reality provides an ideal mechanism for assessing route learning skills more directly and with potentially greater ecologically validity when compared to some paper and pencil-based neuropsychological tests (Rose et al., 2005) and thus facilitate learning and participation. Although it is important to consider that there may be some aspects of real world spatial processing, such as head or body-based movement cues, which may not be fully captured in VR, studies in to the transfer of training of spatial information from VR to the real world (Brooks et al., 1999) and the equivalence across environments are encouraging (Lloyd, et al, 2009a; Sorita et al., 2012) suggest that VR is a useful medium to continue to study aspects of spatial behaviour, which may not be possible in the real world. Therefore, the following two chapters will outline the development of a virtual environment which is used to explore route learning after brain injury. As noted above, whilst a VE may be more akin to real life and thus potentially more engaging than neuropsychological tests, one of the obstacles to be overcome is how to ensure that the real world task demands, such as operating a controller, do not interfere with the task and this is discussed in the next chapter.

CHAPTER 5

USER PREFERENCES FOR VR CONTROLLERS IN TBI AND NEUROLOGICALLY INTACT PARTICPANTS

5.1 Introduction

The following two chapters will outline the development of a virtual environment which will be used to explore route learning after a brain injury. As mentioned in the previous chapter, neuropsychological tests may not always offer the most ecologically valid measure of real world tasks such as wayfinding (Rose, 1996). Virtual reality provides an ideal mechanism for assessing wayfinding skills more directly, with the potential to offer greater ecologically validity and can be used by people with limited mobility (Rose et al., 2005), but this relatively new technology may present practical challenges for people with a brain injury. Therefore, the present chapter will discuss a small study conducted to explore the most suitable type of ‘controller’ (i.e. device used to control movement in the VE, such as a keyboard or joystick) to allow participants to navigate through a 3D virtual world. The following chapter will then detail the development of the VE and, finally, Chapter 7 will describe the experimental study in which the VE was used.

The benefits and rationale for using Virtual Reality in this thesis are discussed in the previous chapter but, lessons learned from previous unsuccessful applications of VR (Stone, 2009) mean that it essential to carefully consider the end user (i.e. the participant/patient) in the development stages and ensure that the methods and apparatus used are suitable for their needs, before the experimental stage is reached. The selection of an appropriate controller is essential, so that working memory capacity is not devoted to the operation of the controller and the operation of the device itself does not distract from the wayfinding task (Rose et al., 2005). Therefore, the current study hopes to find the most suitable controller for use with the virtual environment. In the current thesis, the virtual environment is developed for a study which compares the use of proximal and distal landmarks on a virtual route learning task in people with TBI compared to a neurologically intact comparison group (see Chapter 7). Therefore it was also important to establish whether any differences that might be found in the route learning task could be due to a confound, specifically, a preference for a controller.

A single item question will be used to assess the ease of use of the controllers in this study. The question will be asked “When moving around in the virtual environment, I found this controller easy to use” and answers will be rated on a five point scale ranging from 1 = *strongly disagree* to 5 = *strongly agree*. A second single question will be used to This single item format has been found to correlate well with standard post-task rating scales regarding individual preferences for usability at .91 (Tedesco & Tullis, 2006). It was also preferable to using a longer questionnaire such as the Systems Usability Scale (SUS; Brooke, 1996). Although the SUS has good reliability and validity (Brooke, 1996) and is not lengthy per se, a 10 item questionnaire after each controller may increase fatigue amongst participants and increase acquiescence response bias which can be common with agree/disagree style questions (Krosnick & Presser, 2010).

5.1.2 Aim of the study

The overall aim of this study was to establish user preferences for a controller, which will be used with the virtual environment (as described in Chapter 6) and the rationale for the choice of controllers used in this study is detailed below (Section 5.2.3). The experimental study in Chapter 7 will include both neurologically intact and TBI participants. Therefore, the current study will explore the ease of use and the preference for a controller in both groups of participants. It was also important to establish whether any differences that might be found in the route learning task, in which participants will use a controller to move in the virtual environment, could be due to a confound, in terms of ease of use or a difference in preference for controllers.

5.1.3 Research Questions

This study will explore two specific research questions:

1. Do participants demonstrate a preference for a single controller?
2. Do participants find a single controller easier to use, as judged by a single question “When moving around in the virtual environment, I found this controller easy to use”?
3. Is there a difference between participants with TBI and a neurologically intact comparison group on this single question, rating how easy the controller was to use?

5.2 Method

5.2.1 Design

A repeated measures, matched participants design was employed. Participants with a TBI and comparison group matched for age, gender and computer game use took part in an active navigational task in a virtual environment (Shingari, 2015). Participants were matched on the additional measure of computer use as their experience using controllers with computer games may be superior to those who do not use them (Cánovas, Espínola, Iribarne & Cimadevilla, 2008).

Participants tested four different controllers, one at a time. Immediately after using each controller, participants were asked to rate how easy the controller was to use by responding to the question “When moving around in the virtual environment, I found this controller easy to use”. At the end of the trial, after using all four controllers, participants were asked if they had a preference for a controller by responding to the question “Overall, when moving around in the virtual environment, which controller did you prefer?” and participants were asked to select a controller. The controllers were presented in a random order, to address practice and order effects. Ethical approval for this was granted as part of the main study (Appendix A).

5.2.2 Participants

Firstly, a convenience sample of 12 participants with TBI (six males and six females) were recruited from an outpatient rehabilitation service in the West Midlands. The inclusion criteria were a confirmed TBI which had occurred at least six months prior to beginning the study, the ability to operate a controller with one or both hands, willingness to trial a head-mounted controller (the head tracker) and ability to give informed consent. The exclusion criteria were a very severe memory impairment, marked communication difficulty, poor insight which would make it difficult for participants to answer the questions. The neurologically intact participants were recruited from the University of Birmingham and the additional exclusion criteria for this group was a history of a brain injury, as judged by the participants themselves. None of the participants reported a brain injury. Participants also provided answers to three demographic questions. These were age, gender and level of computer game use. Frequency matching was then employed (Wacholder, et al., 1992) and potential participants from the neurologically intact comparison group were matched to the TBI participants group based on having the same number of participants in each age group (20-29 years, 30-39 years, 40-49 years, 50-59 years), in the same gender category (male or female) and rating the same level of computer game use (never, rarely, occasionally, often) where possible (Boslaugh, 2012).

There were six males and six females in both groups. The data were first checked for missing cases and outliers and none were present. Given that the data for age was normally distributed using the Kolmogorov–Smirnov test, Levene's test for homogeneity of variance was not significant and the data met the criteria for parametric analysis (Field, 2009; Pallant, 2007), an independent samples *t*-test was conducted The results confirmed there was no significant difference between TBI participants (M = 47.67, SD = 10.44 and the comparison group (M = 44.33, SD = 13.78) based on age $t(8)=-.668$, p =.511. Computer game use was assessed using a single question "How often do you play computer games?" and answers were rated from 1=*never*, 2=*rarely*, 3=o*ccasionally*, 4=*often* (Cánovas, et al., 2008). No missing data or outliers were present but as the single item question was categorical data, it did meet the assumptions for a *t*-test or non-parametric equivalent (Pallant, 2007). Therefore, the differences were not tested significantly but frequency data shows that there were the same number of participants in the TBI and neurologically intact groups (*never* = 3, *rarely* = 4, *occasionally* = 3, *often* = 2).

5.2.3 Procedure

Staff at the rehabilitation centre were briefed about the study and the inclusion and exclusion criteria. The key workers provided an overview of the study to potential participants who met the inclusion criteria (as judged by the key workers and in accordance with participant records) and interested participants were asked to approach the researcher, who was on site regularly. The researcher then arranged a time explain the study in further detail and give participants the opportunity to ask questions. All participants were given a minimum of 24 hours to consider whether to participate in the study. Once agreed, appointments were made with participants at their day centre to begin the study. At the beginning of the first session, participants went through the study and were given the opportunity to ask further questions. Participants wishing to proceed, read and signed the consent form (Appendix C). Neurologically intact participants were recruited through word of mouth from a number of sources and these included staff from the rehabilitation service who were aware of the project as they had helped to recruit participants with ABI, colleagues from the University of Birmingham, including staff and students.

After giving informed consent, the testing took place in a quiet room at the rehabilitation centre or at the University (for the comparison group). Participants sat at a desk in front of the computer and the VE was presented via a Samsung R780 Aura Core i5-520M laptop, with a 17” screen on a desk. Participants were asked to explore the virtual environment by walking around for the full 5 minutes. Limited instructions were provided for the controller operation, as the objective was to reduce the working memory demands on participants who may already experience memory difficulties and ensure that the final device was one that was suitable for use by people with TBI.

The four controllers were presented in a random order for a duration of 5 minutes per controller. Participants were encouraged to continue actively exploring for the full five minutes and verbalise their thoughts as they moved around the environment. After using each controller participants were asked to rate the controllers on a single Likert scale statement; “when moving around in the virtual environment, I found using this controller very easy”. Participants had a short 5-minute break while the next controller was set up and the testing and questions were repeated for all four controllers. At the end of the trial, after all four controllers were used, participants were asked “overall, when moving around in the virtual environment, which controller did you prefer?” and answers were recorded.

5.2.3 Apparatus and materials

Four game controllers were chosen for investigation in the study based on previous VR wayfinding studies and discussions with my academic co-supervisor. All four controllers were lightweight, portable and compatible with the Unity (Version 3.4.0, 2010). Unity is a free software toolkit which allows the user to design and build the virtual relaity environment and this is described further in Chapter 6). The controllers were also judged to be affordable if the system was to be used within rehabilitation settings and the NHS. The price of the widely available joystick, Xbox controller and keyboard/mouse was approximately £30 - £40 at the time of purchase (2010). The head tracker was a more expensive option but the reasons for the inclusion of this controller are discussed in more detail below.

5.2.3.1 Joystick

According to Wallet, Sauzéon, Pala, Larrue, Zheng et al., (2011, p. 418), “the use of a motor interactor, such as a keyboard or a joystick, was very early on thought of as a tool allowing the better integration of a route”. Over the past decade, the joystick has been one of the most commonly used game controllers in wayfinding studies (Mellet, Laou, Petit, Zago, Mazoyer et al., 2010; Ruddle, Volkova, Mohler & Bülthoff, 2011) and has been successfully used in a number of a studies with people with brain injury (Kober et al., Livingstone & Skelton, 2007; Skelton, Bukach, Laurance, Thomas & Jacobs, 2000). The joystick can be operated using one hand, which makes it particular suitable for participants who have restricted movement e.g. after a stroke. The joystick (“Logitech Joystick 3D Extreme Pro”, 2010. See Figure 5.1) was used in this study, as it provided a balance between cost and function.

Figure 5.1: Logitech joystick *(online image) Retrieved 28th November from*: *from http://gaming.logitech.com/en-gb/product/extreme-3d-pro-joystick*

5.2.3.2 Keyboard and mouse

The traditional keyboard and mouse combination has also been used in wayfinding studies (Goerger, Darken & Boyd, 1998; Meijer, Geudeke & Van den Broek, 2009; Weisberg, Schinazi, Newcombe, Shipley & Epstein, 2014) but has not been used as frequently with brain injured participants, as their use requires the mobility and coordination of both hands. However, the keyboard and mouse were deemed suitable for inclusion in the study as they are the most likely of all the controllers to have been used by the participants at home or at work. Research suggests that one of the best predictors of the use of memory aids after a brain injury can be pre-morbid use and the ability to learn to use the device itself (Evans, Wilson, Needham & Brentnall, 2003). In the case of wayfinding difficulties after a brain injury, where functional independence and the ability to learn new technologies may already be reduced (Gartland, 2004), participants may have used a keyboard and mouse prior to their injury and therefore, may be more likely to do so again.

5.2.3.3 X Box

The controller ("Microsoft's Xbox 360 controller", 2010. See Figure 5.2) uses 2.4 GHz wireless technology and is powered by a rechargeable battery pack. The controller is also compatible with PCs using a wireless gaming receiver and, therefore, would be suitable for repeated use within a research or NHS setting. Xbox controllers are usually selected by researchers for VR studies based upon the anticipated familiarisation of the user with the device (Stone, 2012) and are more frequently used in studies where participants are familiar with gaming controllers or have computer game experience, such as supporting students in education (Pearson & Bailey, 2008) or training in the armed forces (Sanchez & Smith, 2007). However, the close proximity of the button layout allows the user to reach all of the controls easily and this may be an advantage for participants who may find it difficult to search for keys on a keyboard.

Figure 5.2 *Xbox 360 controller (online image) Retrieved 1st November 2014 from http://www.microsoft.com/hardware/en-us/p/xbox-360-controller-for-windows*

5.2.3.4 Head Tracker

The head controller (“TrackIR Head Tracking System”, Natural Point, 2010. See Figure 5.3) was also tested in the present study. This is a small (2" x 1.5" x 0.57"), lightweight (1.8 oz) system which attaches to a baseball cap and allows the user to control their view in the VE by moving their head (i.e. looking left corresponds with looking left in the VE). The field of view is 51.7 degrees and a keyboard is used in conjunction with the device to control forward and backward motion. Head trackers are suitable for gaming environments but have also been used for game-based training such as flight training (Le-Ngoc & Kalawsky, 2013). The head tracker was the most expensive of the controllers (approximate price £150) but was deemed suitable for inclusion because it offered a more natural control of the view and may be more suitable for participants who find it difficult to learn new controls such as the Xbox.

Figure 5.3: *TrackIR Head Tracking System by Natural Point (online image) Retrieved 31st October 2014 from http://www.naturalpoint.com/trackir/02-products/product-how-TrackIR-works.html*

5.2.4 Virtual environment (VE)

The VE was a simulation of the Strathcona building and the surrounding area based on the University of Birmingham campus (Shingari, 2015). The VE was designed to provide an arena in which participants could freely explore but with enough complexity to test the full function of the controls (e.g. going through doors, negotiating stairs, turning in small spaces). Images of the environment are shown below in Figure 5.4.

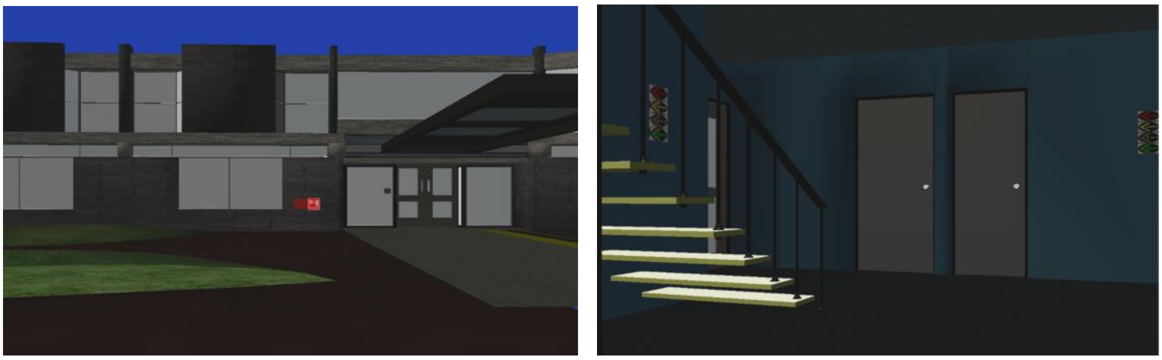

Figure 5.4: *Screenshots from the virtual environment*

5.4 Results

5.4.1 Do all participants demonstrate a preference for a single controller?

Figure 5.5 shows the frequency of controller preferences after all four controllers had been used. The pattern of responses was extremely similar for both groups and the majority of participants demonstrated a preference for the joystick.

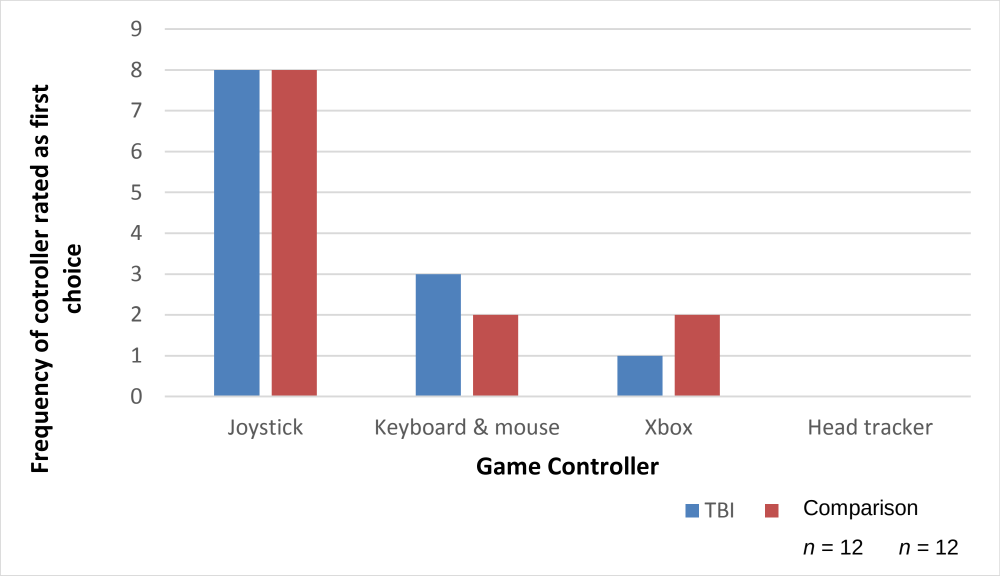

Figure 5.5: *Frequency with which each controller was rated as first choice*

5.4.2 Is there a difference between controllers based on ease of use rating?

Table 5.1 shows the means and standard deviations for the ease of use rating for each controller. Participants with TBI and the comparison group reported that the joystick was the easiest to use, followed by the keyboard and mouse, Xbox controller and finally the head tracker.

Table 5.1: *Descriptive statistics and results of the Mann-Whitney test for the ease of use of the four controllers*

	Neurologically intact participants		TBI participants			
	Median	Range	Median	Range	Mann-Whitney *U*	*p*
Xbox	3	1-5	2.5	1-5	69.0	.856
Joystick	4	3-5	4	2-5	62.0	.534
Keyboard	4	3-5	3	2-5	50.0	.174
Head tracker	1	1-2	1	1-3	59.5	.265

Given that the data were derived from Likert scales and did not meet the criteria for parametric statistics (Field, 2009; Pallant, 2007), non-parametric statistics were used to test firstly whether there was a difference in the ease of use between controllers for each individual group (i.e. a within-group comparison) and secondly, whether there was any difference between groups on the ease of use of each controller.

A Friedman's test showed that there was a difference in ease of use between controllers for the neurologically intact group, $X^2(3) = 24.50$, $p < .001$. The mean ranks were 2.21, 3.42, 3.21 and 1.17 for the Xbox, Joystick, keyboard/mouse and head controller respectively. A similar pattern showing a significant difference also emerged for the TBI group, $X^2(3) = 22.49$ $p < .001$. The mean ranks were 2.25, 3.58, 2.88 and 1.29 for the Xbox, Joystick, keyboard/mouse and head controller respectively. Post hoc tests were carried out to explore these differences further using a series of Wilcoxon signed-rank tests, with Bonferroni corrections applied to minimise Type 1 error, resulting in a significance level set at $p < .008$ (p =.05 divided by the number of tests, Field, 2007).

For the neurologically intact participants there were no significant differences between the joystick and Xbox (z = -2.11, p = .035), keyboard/mouse and the Xbox (z = -2.29, p = .022), head tracker and Xbox (z = -2.59, p = .010) or the keyboard/mouse and joystick (z = -.70, p = .490). Two significant differences were found between the head tracker and joystick (z = -3.09, p = .002) and the head tracker and keyboard/mouse (z = -3.13, p = .002).

For the TBI participants there were no significant differences between the joystick and Xbox (z = -2.60, p = .009), keyboard/mouse and the Xbox (z = -1.26, p = .207), head tracker and Xbox (z = -2.36, p = .019) or the keyboard/mouse and joystick (z = -2.23, p = .026). Two significant differences were found between the head tracker and joystick (z = -3.09, p = .002) and the head tracker and keyboard/mouse (z = -2.96, p = .003). The descriptive statistics are shown in Table 5.1.

5.4.3 Is there a difference between participants with TBI and a neurologically intact comparison group in the ease of use of the controller?

For differences between the groups on ease of use of the controllers, a series of Mann-Whitney Tests showed that there was no difference between groups in the reported ease of use for any of the controllers (See Table 5.1).

5.5 Discussion and Recommendation

The present study compared perceived ease of use and individual preference for four gaming controllers to be used in a 3D virtual world. Although not tested significantly, the joystick was rated as the easiest to use by both sets of participants, followed by the keyboard and mouse. Secondly, the results suggest that both groups reported a difference in how easy the controllers were to use and in both groups, the highest mean rank was found for the Joystick, with the keyboard and mouse ranked second highest. The post hoc-tests suggest that the only significant differences for both groups were between the head tracker and keyboard/mouse and the head tracker and joystick, with the head tracker the lowest. Thirdly, there was no difference between groups on usability for any individual controller. Given that the joystick was rated consistently higher on ease of use by both groups and although not tested significantly, was most frequently rated as the preferred controller by both groups, it was decided to proceed with the joystick as the controller for use in the development of the VE and the experimental study, described in the next two chapters.

Finally, it should be acknowledged that the sample size in the current study is small and that the effect of the controller on performance on a VR task was not measured so the results should be interpreted with caution. However, given that the results suggest that there was no difference in the ease of use between groups for the joystick, and this has been selected as the controller which will be used in the virtual route learning task, a difference in perceived usability would be unlikely to influence any potential between group differences in the study in Chapter 7.

Furthermore, given the ease with which the joystick was used and the previous research using joystick to control spatial navigation in VR (Kober et al., Livingstone & Skelton, 2007; Ruddle et al., 2011; Skelton et al., 2000), it was hoped that the controller would not be a barrier to creating an user-friendly virtual environment for the purpose of the study described in Chapter 7.

CHAPTER 6

DEVELOPMENT OF A VIRTUAL ENVIRONMENT FOR ROUTE LEARNING

6.1 Introduction

This chapter will first describe the process used to develop a virtual environment for use in the route learning study, described in Chapter 7. This is followed by the development of two equivalent routes through the virtual environment. One route contains proximal landmarks and the other route contains distal landmarks. Before the routes were constructed, it was first necessary to decide upon which software to use and the evaluation is described below.

6.1.1 Software evaluation

Two 3D modelling applications (software toolkits) were evaluated for their use in this project; Blender (Version 2.49, 2010) and Google SketchUp Pro (Version 8.0.3117, 2010). Primary considerations were ease of use and online support for new users, availability of tutorials which provided clear instructions for modelling (e.g. online videos), ability to run on relatively standard price desktop machines/laptops, being supportive of popular file import/exports and compatibility with games engines which would be used to run the final application. Sketchup was chosen based on these criteria and, although Blender offered superior texture mapping (i.e. the ability to add texture, detail and colour to the 3D models) and low polygon modelling (a less detailed 3D structure with less polygons, which enables a faster, optimised performance) support, there was not enough support for new users and the Sketchup user community provides online models which can be downloaded free of charge.

6.1.2 Game engine

Unity 3D was chosen for use in this project (Unity Virtual reality Games, Version 2.5.0, 2011). Unity is a widely available and free game engine which can be used to develop and run video games on desktop computers. As it was important for this project to develop a cost-effective virtual environment which could be easily used in rehabilitation centres without the use of additional software or hardware, Unity was deemed the most suitable. Unity is well suited to import models from SketchUp which would make the workflow more efficient (i.e. a smaller number of steps were required in order to import the models in to the application). Unity also has access to free online models which could be used in the project.

6.1.3 Hardware

A Samsung R780 Aura Core i5-520M notebook with a 4GB of RAM and NVIDIA Geforce graphics card and 1TB hard drive was used to create, test and run the virtual environment. This model offered a balance between power, durability, portability and visual display. In particular, the 17.5” screen was larger than a standard laptop screen and would make the visual display more suitable for users with mild visual impairments. During the final stages of testing, a Dell XPS 15 with a 4th Generation Intel Core i7 4712HQ processor, 16 GB of RAM, NVIDIA GeForce GT 750M graphics was used. This laptop was used in the later stages as it had a faster processing speed than the Samsung, which was necessary due to the complexity of the virtual environment.

6.2 The virtual route

A virtual street maze was created in order to explore route learning using proximal and distal landmarks (see Chapter 7 for the study). A single maze was created and two different 15-turn routes through the maze were generated by randomly allocating five left turnings, five right turnings and five straight-on decision points. The number of turnings along the route was chosen in order to create a balance between a route which contained sufficient difficulty so as to avoid ceiling effects in neurologically intact individuals or excellent navigators but one that was not so lengthy that it caused participants to become too fatigued or distracted. This decision was supported by previous research which has successfully used between 12-15 turnings in studies with neurologically intact participants (Hartley et al., 2003; Lloyd et al. 2009b) and those with a brain injury (Barrash et al., 2000; Lloyd et al. 2009b; Sorita et al., 2012). The 3D modelling of the routes and the landmarks was completed in Trimble Sketchup Pro; the scenes were constructed to run as a game in Unity and this process is illustrated below.

6.2.1 3D modelling

A semi-detached house model was downloaded from the SketchUp 3D Warehouse (Google Sketchup, 2010) and this model is shown in Figure 6.1 below. The model was scaled to size to represent a standard UK-two storey terraced house; modifications were made to the structure of the building (e.g. to the chimney, adding windows/blinds, creating walls, adding raised curbs); and textures from the SketchUp paint catalogue were applied. This model was then replicated to form a street (Figure 6.2), which in turn was used to create a square block of streets and placed on a scaled grid to form the virtual street maze (see Figure 6.3).

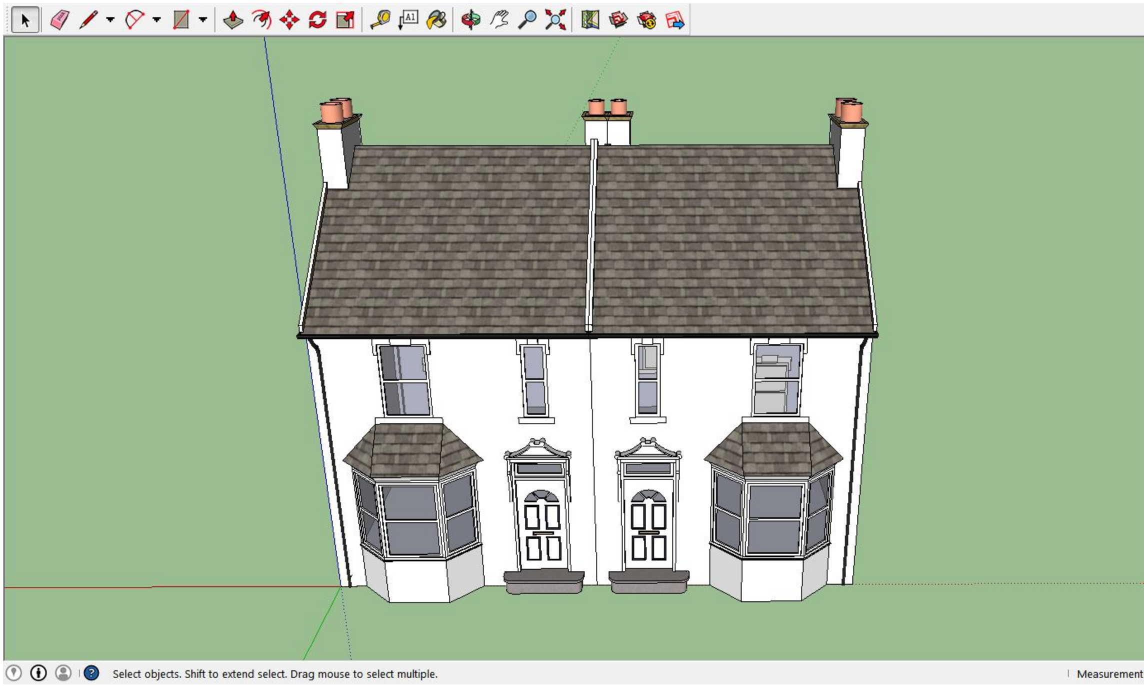

Figure 6.1: *SketchUp house model before further textures were applied*

Figure 6.2: *Model street in SketchUp after the colours, textures and roads have been added*

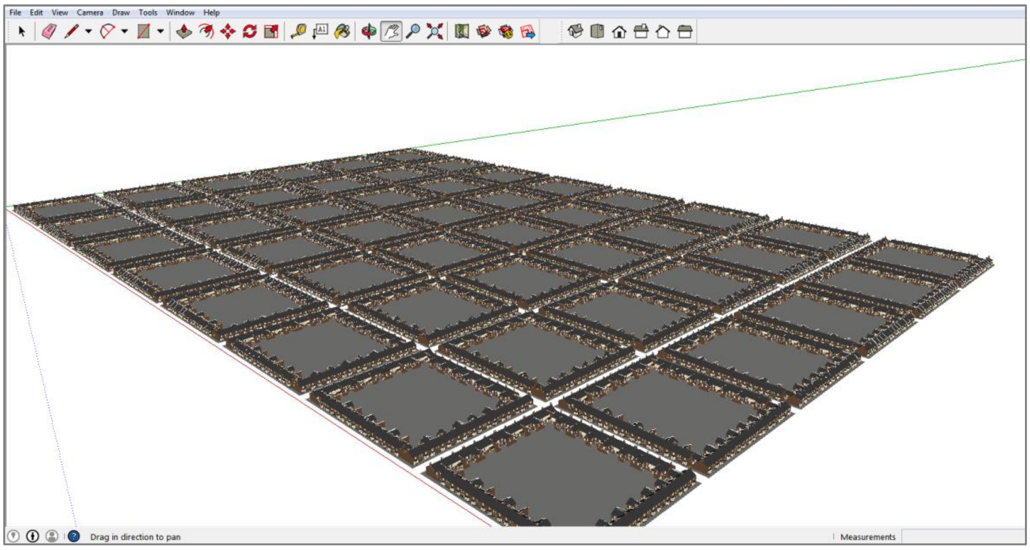

Figure 6.3: *Model street grid in SketchUp*

With the structure of the street maze in place, the files were imported to Unity in .fbx format and placed on a road-textured terrain (texture acquired from the Unity texture catalogue – see Figure 6.4). Shading was adjusted and a skybox (a surrounding sky scene including blue sky and clouds which remain fixed to the viewing angle so as not to provide additional directional/orientation cues), camera and a first person controller were added to create an outdoor scene. The camera was positioned at approximate head height and would therefore provide the view of the streets for the participant during testing. The first person controller allowed the participant to move through the virtual environment and this was programmed with a script (a series of instructional codes), so that the movement in the VE was controlled using the joystick.

Figure 6.4: *Street model in Unity 3D*

Participants are guided around the route by yellow arrows. The arrows were chosen as they are a common directional symbol and were less likely to interfere with the working memory demands of the task or individual preference for audio, map-based or written instructions (Lemoncello, Sohlberg & Fickas, 2010a). They were also more suitable directional symbols for people may have difficulty processing verbal instructions (e.g. turn right) or keeping these instructions in memory (e.g. turn right at the end of the street). The arrows were created in SketchUp, imported into Unity and placed at the appropriate points on the terrain using the same method described above. A script was attached to each arrow which played a sound when the participant passed it to reassure the participant they were going the right way.

Markers were placed at the start and finish lines of the route so that these were clearly visible to participants when they were approached (see Figure 6.5). A script was attached to the start line object which played a sound when the participant crossed the start line, displayed all the arrows on the learning trials and hid the arrows on the final test trial (where participants had to remember the route themselves without guidance). The script attached to the finish line object played a sound when the participant crossed the finish line and returned the participant to the start of the route to begin their next lap.

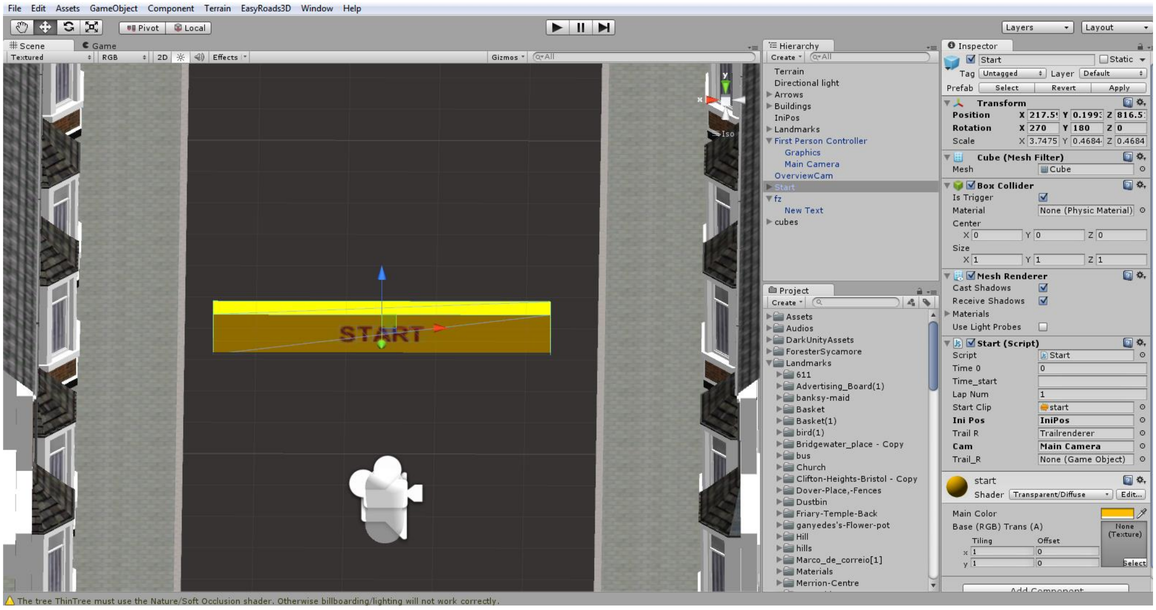

Figure 6.5: *Start bar and viewing camera position in Unity 3D*

6.2.2 Route equivalence

A pilot study was conducted to test whether the two routes were equivalent with regards to route learning performance, before the landmarks were added. A convenience sample of 16 undergraduate students from the University of Birmingham took part in a within-subjects route learning test (following the same procedure described fully in Chapter 7). The order of the routes was counterbalanced and the routes, which would later be assigned to either proximal or distal landmark conditions, were tested for equivalence. In the first session, participants completed three laps of one route following the yellow directional arrows and on the fourth lap, the arrows were hidden and participants had to repeat the route from memory. On the second session, participants completed the second route following exactly the same procedure. The outcome measures were the number of correct turns on the fourth lap (maximum of 15). No missing data or outliers were present and the data met the criteria for parametric analysis, namely the data were normally distributed, the assumptions for homogeneity of variance were not violated according to Levine's test, there were matched pairs measured on one categorical independent variable (route A/B) and one continuous dependent variable (route learning score) was tested, (Field, 2007; Pallant, 2007). Therefore, a paired samples *t*-test was conducted. This showed that there was no significant difference between the scores for route A (M = 10.5, SD = 2.83) and route B (M = 10.26, SD = 2.94) on the route learning task without landmarks; $t(15)=1.17$, $p = .261$. Although some caution should be exercised in the interpretation of results from a small sample size, given that route learning performance did not differ significantly across the two routes without landmarks, they were deemed suitable for inclusion in the study and the next section will summarise how the proximal and distal landmarks were selected and added to the virtual environments.

6.2.3 Landmarks in the virtual environment

Before the landmarks were added to the VE, it was first necessary to define what is meant by the term ‘landmark’ and which type of landmarks will be used. Many definitions exist as to how to define a landmark and what makes a landmark salient (Chan, Baumann, Bellgrove & Mattingley, 2012; Golledge, 1999; Lynch, 1960; Presson & Montello, 1988; Röser, Krumnack, Hamburger & Knauff, 2012; Sorrows & Hirtle, 1999). Overall, a landmark is an external reference point (Lynch, 1960), which is visually contrasting to the surrounding environment (Presson & Montello, 1988) and contains properties which are prominent to the observer (Caduff & Timpf, 2005). The last authors suggest that, in order for a landmark to be attended to and used during wayfinding, it must hold perceptual, contextual and cognitive salience (Caduff & Timpf, 2008). Firstly the term ‘perceptual salience’ refers to the physical properties of the landmark (i.e. colour, shape, size, texture, contrast), which capture the navigator’s visual attention (Röser et al., 2012). For example, a tall, red house may have high perceptual salience but in a street made up of tall, red houses, it may have low perceptual salience. The term ‘contextual salience’ refers to the way in which the context or the type of task affects the navigator’s visual attention and the amount of resources which are assigned to it. For example, learning a route which contains many landmarks may require more resources to select and attend to the landmarks which are more relevant for navigation, when compared to a route which only contains several landmarks. Finally, the term ‘cognitive salience’ refers to the properties of the landmark which are personally meaningful to the individual and are dependent on the experience of the individual. For example, a petrol station may be a landmark with high cognitive salience for a car driver but it may hold low cognitive salience for someone who does not drive. Although this framework offers a way to conceptualise the way in which landmarks may be salient, there is no widely accepted or agreed method to determine the salience of landmarks (Röser et al., 2012). Previous route learning studies have used a variety of stimuli as landmarks including pictures of everyday objects such as fruit, animals, household objects (Ruddle et al., 2011; Wiener et al., 2012), textured shapes (Hurlebaus et al., 2008; Röser et al., 2012) and objects found in an office (Janzen, 2006). However, in order to ensure ecological validity in an outdoor environment, the objects clearly need to be relevant to the context and scaled to size for that environment. However, it is not possible to provide ecologically valid landmarks that hold the same saliency for every individual; as Caduff and Timpf (2008) suggest, this type of saliency will be dependent on the experience of the navigator. Therefore, with an emphasis on ecological validity, the current study used a range of everyday objects, which would be found in an outdoor environment (see Appendix G). This was in line with previous studies which have used more naturalistic outdoor virtual environments (Brooks et al., 1999; Hartley, et al., 2003; Lloyd et al., 2009b; Sorita et al., 2012) and it was hoped that this would provide a balance between experimental control and ecological validity.

However, saliency is also important in relation to the appearance of the object itself. Davis, Therrien and West (2009) explored the effect of different levels of saliency in a virtual wayfinding task and created three versions of their virtual environment: Non salient (a greyscale room which lacked colour, texture and recognisable cues which could provide perceptual or cognitive salience), simple salient (black and white room with four prominent pictures on the walls but the room lacked colour) and a complex salient condition (coloured and textured room with textured brick walls, colourful pictures, distinguishing features such as arches and these were designed to provide meaningful cues). The authors found that wayfinding performance was better in the complex salient landmark condition and therefore, in accordance with these findings, the current study used everyday outdoor objects as landmarks which were both coloured and textured.

In order to explore the use of each type of landmark, two versions of the street maze were created; one containing only proximal landmarks and one containing only distal landmarks using the routes from the pilot study (see Appendix H). Each route contained 15 turns and one landmark was placed at each turning/decision point along the route in line with research which suggests an attentional preference for objects at decision points (Janzen, Jansen & van Turennout, 2008) and consistent with previous route learning studies in VR (Janzen, 2006; Ruddle et al., 2011; Wiener et al., 2012, see Figure 6.6 for example).

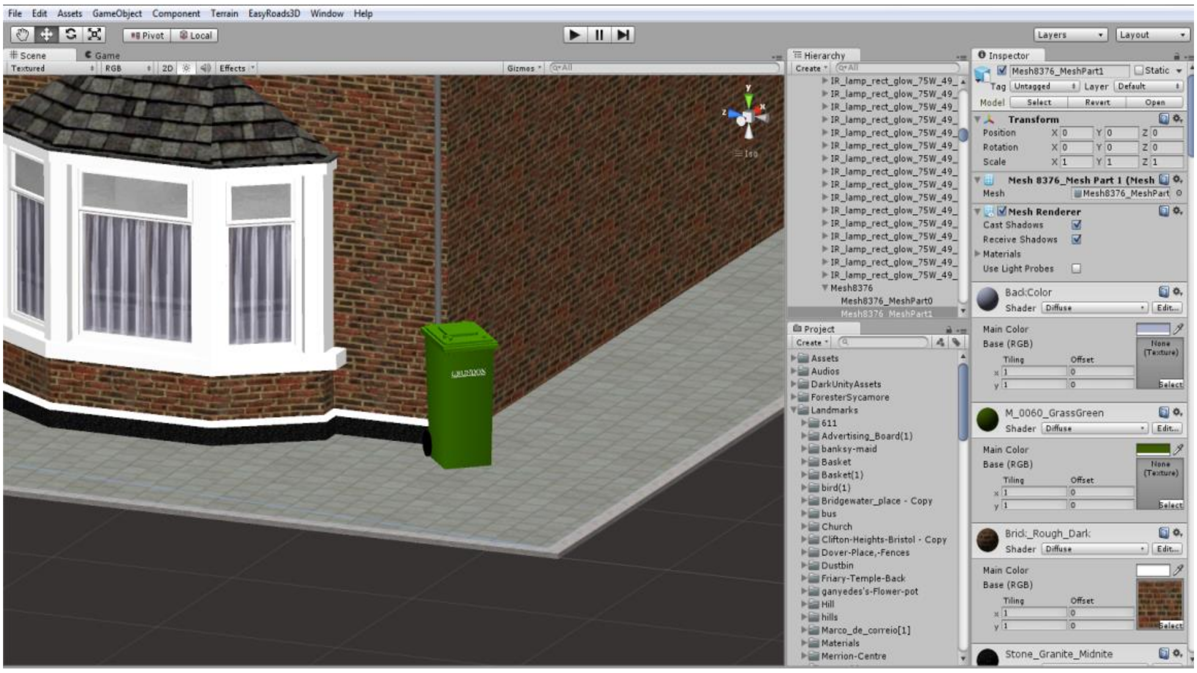

Figure 6.6: *Proximal landmark positioned in Unity*

Figures 6.7 and 6.8 show the potential positioning of the proximal and distal landmarks at a decision point (Röser et al., 2012, p. 83). Each landmark could be placed at one of four positions corresponding with the participants' field of view (marked A-D on the diagram). The landmarks were randomly allocated to one of the four positions at each decision point along the route.

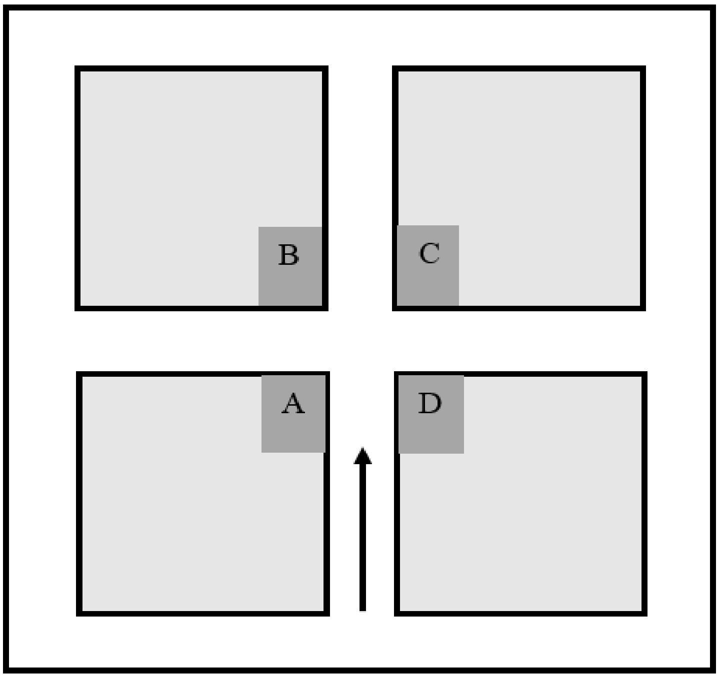

Figure 6.7: *Proximal condition landmark positioning at an intersection, based on the diagram in Röser et al., (2012, p. 83).*

Figure 6.8 (overleaf) shows the four potential positions for a landmark (A-D), based on the field of view of the participant (the viewers position is indicated by a black circle on the diagram). Landmarks placed outside the field of view will not be visible and thus, not appropriate for the route learning task described in Chapter 7. The white space in between sections B and C on Figure 6.8 indicate that no landmarks are positioned in this space, so they cannot act as ‘beacons’ (i.e. the correct turning can be made by simply walking to the landmark).

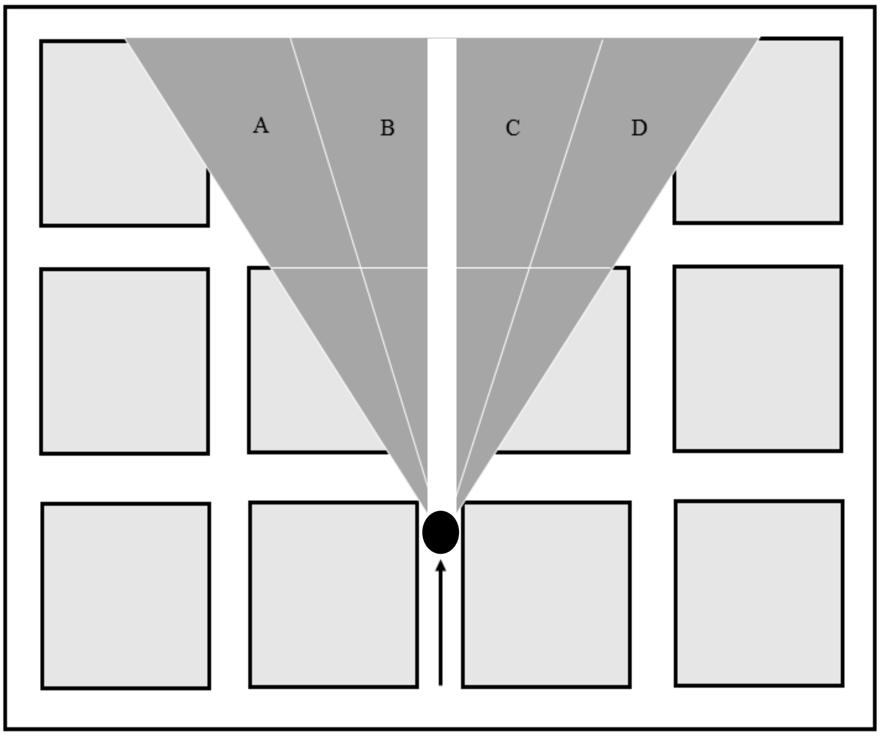

Figure 6.8: *Distal condition landmark positioning, based on the diagram in Röser et al., (2012, p. 86).*

Previous studies exploring the positioning of landmarks have shown that people demonstrate a preference for landmarks that act as beacons (Waller & Lippa, 2007), where the position of the landmark indicates the goal location and the correct route can be taken by walking directly towards the landmark. Therefore, each proximal landmark in the current virtual environment is positioned directly on the corner between two streets, so that using it as a beacon is not possible and walking towards it would send the participant directly in to a building, rather than along the correct route. Distal landmarks have also been positioned randomly at one of four positions in the field of view of the participants when they approach the choice point. Again, using the landmark as a beacon and walking directly towards it would send the participant into a building and not along the correct route. This positioning was chosen rather than the complete removal of all landmarks which may perceived as in the direction of turning as this may also affect the experiment should participants learn the pattern that there is never a landmark in the correct direction and use this strategy to repeat the route, rather than rely on memory. Thus the most parsimonious solution was to randomly allocate the position of landmarks.

The decision to allocate one landmark to each turning point was to ensure that both conditions contained the same number of landmarks and to avoid forcing participants to use a particular type of spatial strategy. If more than one proximal landmark was placed at a turning point, an additional allocentric strategy could be utilised (i.e. using the spatial relations between the two landmarks to determine their position and remember the route). Previous research suggests that participants with TBI may have difficulty using allocentric strategies (Livingstone & Skelton, 2007) and, therefore, the addition of more than one landmark in the proximal condition may not only introduce an experimental confound but also severely disadvantage these participants.

In the current VE, the distal landmarks were scaled to the size of the other buildings in the environment and were tall enough and to make them visible above the intervening buildings. This inevitably resulted in a small amount of the landmark which was not visible but in order to create a naturalist environment which reflected real world distal landmarks, it was decided not to make the landmarks disproportionately large or raised up from the ground, so that they did not appear more distinctive or perpetually salient than the proximal landmarks, which may have affected the results of the route learning tests. Participants in the route learning task will be asked to call out the landmarks on the first learning trial, to ensure that all proximal and distal landmarks were both visible and identifiable and this is described next in Chapter 7.

CHAPTER 7

THE USE OF PROXIMAL AND DISTAL LANDMARKS FOR VIRTUAL ROUTE LEARNING

7.1 Introduction

This chapter will first discuss how aspects of the pathophysiology of traumatic brain injury impacts on wayfinding. It will then provide a narrative account of the studies of landmark use in wayfinding and place learning, including studies using the Morris Water Maze. It will then introduce previous research exploring the use of proximal and distal landmarks in place learning in people with traumatic brain injury (TBI) which suggests that proximal landmarks are used more efficiently by people with TBI and could, therefore inform rehabilitation strategies. These studies form the basis of the present study. Finally, the importance of landmarks for route learning is explored and a study is then carried out which compares the use of proximal and distal landmarks for route learning in people with TBI.

7.1.1 Wayfinding, traumatic brain injury and hippocampus

Traumatic brain injury (TBI) can be defined as “an alteration in brain function, or other evidence of brain pathology, caused by an external force” (Menon, Schwab, Wright & Maas, 2010, p. 1637) and closed or non-penetrating TBIs constitute approximately 70% of all head injuries (Ponsford, Sloan & Snow, 2012). The injury often results in diffuse axonal injury and post-traumatic amnesia, which can be accompanied by short and long term neurological impairment (Maller & Reglade-Meslin, 2014). Memory problems are one of the most common consequences of TBI (Vakil, 2005; Wilson, 2013) but the impact upon wayfinding and specifically route learning, is one of the least understood (Aguirre & D'Esposito, 1999).

Wayfinding studies generally distinguish between two different cognitive strategies, which have been associated with different anatomical areas (see Chapter 2). Egocentric or body-centred strategies tend to involve a series of navigational responses associated with cues such as proximal or distal landmarks (Trullier et al, 1997; Waller & Lippa, 2007) which have been linked with activity in the caudate (Burgess, 2008; Iara et al, 2003). Alternatively allocentric or cognitive mapping strategies centred on the environment use the spatial relationships between objects to derive information. Allocentric strategies which involve forming a cognitive map may rely on proximal landmarks for place recognition and distal landmarks for orientation cues (Jacobs & Schenk, 2003, Livingstone & Skelton, 2007) and have been linked with hippocampal activity (O'Keefe & Nadel, 1978). This concept has specific implications for people with TBI because although injury severity and locus may vary, some authors have suggested that the hippocampus may be particularly vulnerable to TBI (Atkins, 2011; Kotapka, Graham, Adams & Gennarelli, 1992; Mañeru, Serra-Grabulosa, Junqué, Salgado-Pineda, Bargalló, et al., 2005; Tate & Bigler, 2000; Tomaiuolo, Carlesimo, Di Paola, Petrides, Fera et al., 2004), whilst the caudate is less likely to be affected by the injury (Serra-Grabulosa., 2005; Wilde, Bigler, Hunter, Fearing, Scheibel et al., 2007).

Tomaiuolo et al. (2004) for example, found a reduction in hippocampal volume based on evidence from MRI in people with severe non-penetrating TBI who were at least 90 days post-injury, compared to neurologically intact controls. Two more recent studies have elaborated on this. Green et al. (2014) found that at least 70% of people with TBI (longer than five months post-injury) and ranging from complicated mild to severe, showed a reduction in hippocampal volume. Similarly, Singh et al. (2014), found that American football players showed a reduction in hippocampal volume generally, compared to controls, and this correlated with years of play and was greater if they had also experienced concussive episodes. The role of the hippocampus in wayfinding is likely to include a general memory component as it is a key structure in the formation of long term memory (Jeneson & Squire, 2011), as well as the functions related specifically to wayfinding (Bird & Burgess, 2008; Burgess et al., 1999; Hartley et al., 2003; Maguire et al., 1998; O'Keefe and Nadel, 1978; Shelton & Gabrieli, 2004; Schinazi & Epstein, 2010; Voermans, Petersson, Daudey, Weber, van Spaendonck et al., 2004. See Chapter 2) and these specific functions are beginning to be delineated more clearly.

As discussed in Chapter 2, allocentric processing and the formation of cognitive maps has been associated with the hippocampus (Astur, Taylor & Mamelak, 2002; D'Hooge and De Deyn, 2001; Oswald, Bannerman, Yee, Rawlins, Honey et al, 2003; Parslow et al., 2004; Save and Poucet, 2000) and more recently supported by the discovery of place cells in the hippocampus (Ekstrom, Kahana, Caplan, Fields, Isham et al., 2003). In contrast, egocentric processing, which may be important for route learning (Golledge, 1999), may be more reliant upon the caudate (Bohbot et al., 2004; Iaria et al., 2003). However, how the two strategies interact is not yet fully understood. Some research suggests that they operate within a hierarchical structure where egocentric or route-based knowledge is developed first, followed by allocentric or survey knowledge (Siegel & White, 1975). Other research suggests the two may exist in parallel (Burgess, 2006) or that conversions may take place depending on the type of strategy required to complete the task (Carelli, Rusconi, Scarabelli, Stampatori, Mattioli et al., 2011). For example, looking at a map of a University campus provides allocentric information about the environment but working out where you are on that map may require mental transformations. You would need to use your current position and viewpoint (i.e. the station is in front of me now) and integrate that with the allocentric map-based information to find your position on the map.

Descriptions of route learning emphasise the egocentric nature of the task, where the goal is to learn a specified sequence of turnings, rather than to learn the environment through which the route passes (Golledge, 1999). Route learning is often conceptualised as an egocentric task as it involves constantly processing and updating information relative to the position of the self (e.g. turn left) as a route is traversed (Hartlely et al., 2003; Iaria et al., 2003; Igloi et al, 2009; O'Keefe & Nadel, 1978, Tolman, 1948). Route learning is an everyday task that is useful for some aspects of community travel and previous literature investigating the link between brain injury and wayfinding suggests that route learning impairments may be common after TBI (Barrash, 1998). However, the literature has primarily focussed on case study descriptions of topographical disorientation and/or people with focal lesions (Antonakos, 2004; Rainville et al., 2005). These case studies are discussed in greater detail in the next chapter (see Chapter 8) but given that closed or non-penetrating TBIs may constitute approximately 70% of all head injuries (Ponsford et al., 2012), this individualised focus on case studies makes it difficult to draw conclusions about how to make practical recommendations for rehabilitation.

As previously discussed, there are a lack of ecologically valid assessments for wayfinding impairments and instead, paper and pencil tests tend to draw upon the constituent cognitive processes but do not reflect real world navigational scenarios encountered by people in their daily lives, such as remembering their route to work (see Chapter 4). As a result of this, wayfinding impairments may not become apparent until after the patient has left rehabilitation, when less professional support is available (Koenig, 2012). Virtual reality versions of real world environments offer great potential to bridge the gap between the rehabilitation environment and the real world but in a way that is safe, supported and controlled. It also allows for assessment and rehabilitation to take place much earlier on. For example, a virtual wayfinding task or assessment can be completed from a chair or a hospital bed, before the patient is able to walk themselves and this has great potential to improve recovery outcomes and potentially target plastic changes in the brain. Virtual reality scenarios are also hugely beneficial for researchers as they offer a high degree of stimulus control, experimental manipulation and allow for the repeated presentation of stimuli that may not be possible in the real world, particularly with a physically demanding task such as walking a route. Growing research evidence suggests that performance on wayfinding tasks in virtual reality is equivalent to the real world (Lloyd et al., 2009a) and that learning transfers to the real world (Brookes et al., 1999; Darken & Banker, 2008; Farell et al., 2003; Sorita et al., 2012; Wallet, Sauzéon, Larrue & N'Kaoua, 2013). Therefore, the current study will use a virtual environment for the route learning task to explore the mechanisms and skills which may be spared in TBI, with a view to using the information gained to improve real world route learning for individuals with navigational impairments after a brain injury.

7.1.2 The role of landmarks in wayfinding and the Morris Water Maze

Much of our understanding of the way in which different landmarks contributes to wayfinding tasks has been investigated in early animal studies using the Morris Water Maze (Morris, Garrud, Rawlins, & O'Keefe, 1982) and this has laid the foundations for further human studies in this area. The Morris Water Maze (MWM) typically consists of a large circular arena filled with opaque water, which is too deep for the animal to stand in. No proximal cues/landmarks are available in the maze, only cues such as distal objects in the experimental room itself (e.g. light switch, door etc). The animals are put in to the maze from a variety of different starting positions and are removed from the maze when they swim on to a hidden platform, which remains in a fixed position. Learning is measured by the time taken to find the platform and this decreases over the trials as learning takes place. During a test trial, the position of the platform is moved and the route and time taken to find the platform are measured. During this trial, the animals usually take a lot longer to find the platform and tend to repeatedly search for the platform in the previously trained position. This indicates ‘place learning’ (Tolman, 1948; i.e. navigates to a specific place but can take any route to achieve this goal) as the animals had learned and remembered the place of the platform from the previous trials, using an allocentric strategy (i.e. the relationship between the platform and distal cues in the room), as no proximal landmark cues were available.

A significant finding from the MWM is that rats with hippocampal lesions demonstrated impaired performance on the maze when using patterns of distal cues (Eichenbaum, Atewart & Morris, 1990; Morris et al., 1982). However, with the addition of proximal cues, the same animals were able to find the platform quickly. It has been proposed that, in this case, animals with hippocampal lesions can find the hidden platform based on a stimulus-response association with a proximal landmark next to the platform or alternatively, using heading vectors (heading in a fixed direction towards the hidden platform), rather than using a cognitive map (Pearce, Roberts & Good, 1998; Tolman, 1948). These findings have also been extended to human place learning studies based on the MWM, with neurologically intact participants (Astur, Ortiz & Sutherland, 1998; Bohbot et al., 2002; Bohbot & Corkin, 2007; Cánova et al., 2008; Schmitzer-Torbert, 2007). In one study, Bohbot, Kalina and Stepankova (1998) recreated the paradigm by hiding a noise emitting sensor under the carpet of a room. Participants were required to locate the hidden platform (in this case the sensor) by stepping on it and the task differentiated participants with right hemisphere hippocampal lesions from the control group. More recent variations have included a virtual reality version of the arena maze (Livingstone & Skelton, 2007), which is performed entirely on the computer and is described in more detail below.

It is then surprising that given the sensitivity of the MWM to distinguishing hippocampal lesions in animals and humans, as well as informing our understanding of animal models of TBI (Hamm, O'Dell, Pike, & Lyeth, 1993; McIntosh, Yu & Gennarelli, 1994), relatively few studies have used variations of the MWM paradigm to assess these impairments in individuals with TBI (Bohbot et al., 2002). The obvious practical constraints of creating a physically demanding task for people with

TBI has limited the potential to recreate these types of spatial tasks, particularly for people with cognitive or physical difficulties. However, the MWM was an important development in the understanding of spatial learning and memory, particularly in the role of the hippocampus and the use of different types of landmark-based strategies. It offered a standardised paradigm with which to assess spatial learning and memory and has been a hugely influential paradigm in contributing to our understanding of egocentric and allocentric processing, as well as the brain regions involved in these processes.

Although the ecological validity of a water-based swimming paradigm for humans may be questionable and caution should be applied when interpreting data from animal studies and applying it to human participants (Taube et al., 2013), it does allow for a high degree of experimental control (e.g. positioning of proximal and distal landmarks), which is very difficult to achieve in the real world. The advancements in VR technology (Riva, 2005), accompanied by research supporting the transfer of wayfinding skills from the virtual to the real world (Brookes et al., 1999; Darken & Banker, 2008; Farell et al., 2003; Sorita et al., 2012; Wallet et al., 2009) and the equivalence across virtual and real world environments (Lloyd et al, 2009a), has meant that it is now possible to recreate this paradigm in a more ecologically valid way. Therefore, the current study has a taken another step towards improving ecological validity in the assessment of route learning by creating a task which is performed on realistic, virtual streets, which may increase the potential to apply these finding to real world behaviour and subsequently, to rehabilitation.

7.1.3 The use of proximal and distal landmarks for place learning in people with TBI

One group of researchers have used a virtual reality MWM to explore the nature of wayfinding deficits after TBI using proximal and distal landmarks and these are reported across three studies (Goodrich-Hunsaker, Livingstone, Skelton & Hopkins, 2010; Livingstone & Skelton, 2007; Skelton et al., 2000). This chapter will focus on Livingstone and Skelton's 2007 study, which included participants with TBI, as in the current study. However, the procedure used across all three studies is similar. The authors compared the performance of a group of 11 people with TBI and 12 neurologically intact participants, matched for age, on a place learning task using a virtual maze. Participants completed a series of tasks and these took place in three different mazes, beginning with the arena maze (Figure 7.1, picture A).

In this maze, participants first completed exploration trials and a trial to navigate to a visible platform. The starting position was varied across trials so that participants were not able to use a response strategy (e.g. upon entering the arena, always turn right). The purpose of the first part of the arena maze was to familiarise participants with the environment and the task procedures (e.g. use the controller to navigate to the visible platform), before the platform was hidden. Next, participants had to locate a hidden platform by actively exploring the arena (no proximal cues were present, only distal cues in the form of hills, mountains, a lake, an island etc) and the platform became visible when it was stepped upon. This was designed to test the use of allocentric strategies, as no proximal cues were present. After ten invisible platform trials, a probe trial was completed where no platform was present.

The arena was divided into four quadrants and time spent searching for the platform in the correct place/quadrant from the previous trial was recorded. Longer dwell times in the correct quadrant were taken as a measure of learning.

Next participants completed the single object maze (Figure 7.1, picture B). This involved navigating to a hidden platform which was placed next to a distinctive proximal landmark (a golden urn). This task was designed to test the ability to associate the platform with a single proximal object (i.e. an egocentric strategy). Finally, participants completed the ambiguous maze in which eight proximal landmark objects were placed around the arena walls and the hidden platform was again, placed next to a distinctive proximal landmark (Figure 7.1, picture C). This was designed to allow participants to find the hidden platform using either an egocentric strategy (by a distinctive proximal landmark) or an allocentric strategy (its position in the room relative to distal cues) or a combination of both. It was also designed to test whether participants could select the appropriate landmark which was located next to the hidden platform (the golden urn) amongst a selection of other proximal objects.

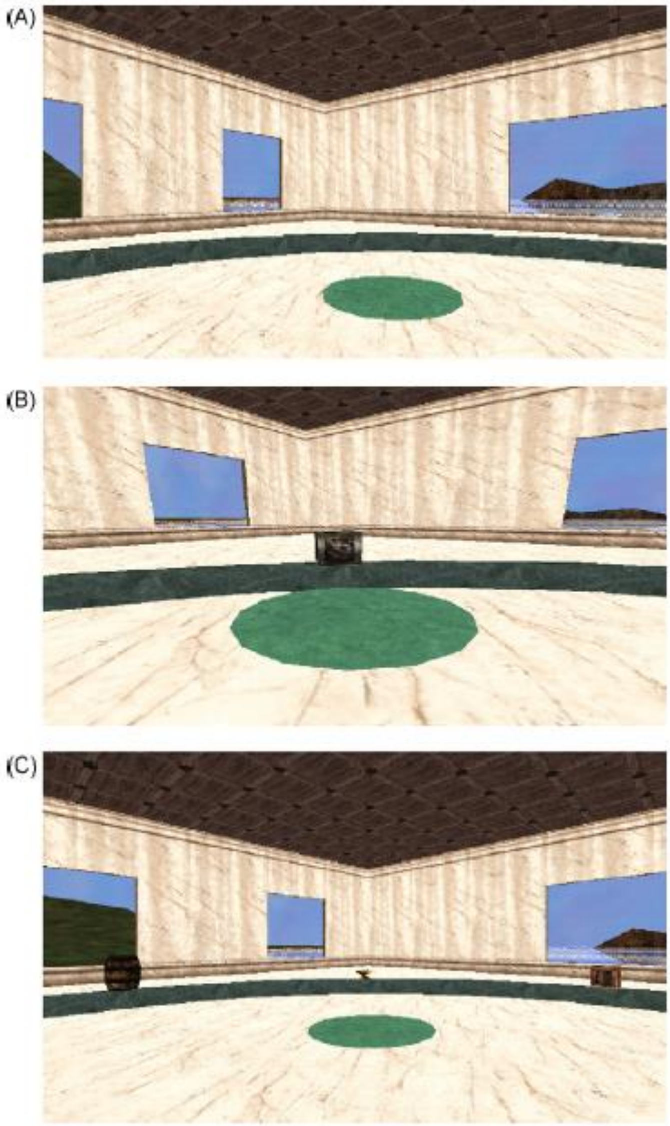

Figure 7.1: *The virtual mazes used by Livingstone & Skelton (2007, p. 23) consisting of (a) the Arena Maze; (b) the Single Object Maze; (c) the Ambiguous Maze*

After the maze trials, participants also completed a series of tests including a clock drawing task to screen for visuo-spatial neglect; a “Where’s the door test” to test whether participants felt as though they were really present/immersed in the virtual world (participants are asked to point to the location of the virtual arena door and higher scores are awarded for pointing to places in the testing room, whereas as lower scores are awarded for pointing to the computer screen); a navigational strategy questionnaire; object recognition test of proximal landmarks from the maze; room reconstruction tasks to assess memory for the spatial layout of the room; an everyday spatial questionnaire developed by the authors; and the Rivermead Behavioural Memory Test (Wilson, Cockburn & Baddeley, 1985) which is a neuropsychological test of everyday memory.

The overall results demonstrated that people with TBI could locate a hidden platform over a series of trials when the platform was placed next to a distinctive proximal landmark (single object maze) but performance was significantly impaired compared to the comparison group, when proximal cues were not available (arena maze). There was no significant difference between TBI and comparison groups on the single object maze, indicating that both groups were able to understand the requirements of the task and associate a distinctive proximal landmark with the location of a hidden platform.

The results of the ambiguous maze trials show that people with TBI performed as well as the comparison group in finding the hidden platform but that navigational strategies differed. Fifty percent of the comparison group reported finding the hidden platform by its location in the room (allocentric) but none of the people with TBI participants reported using this strategy or using the distal landmarks. In contrast, the self-reported use of proximal landmarks was similar in both groups, with 64% of TBI participants and 75% of the comparison group reported using the golden urn. It is not possible to know whether participants with TBI did not report using distal landmarks because they simply did not attend to them, use them or remember them but their self-reported use of a proximal landmark suggests that they may have been aware of the strategy they were using when proximal landmarks were available. Research suggests that increased awareness has been associated with better rehabilitation outcomes (see Ownsworth & Clare, 2006 for a review), so this suggests that further exploration into the use of proximal landmarks in route learning may have the potential to benefit rehabilitation of wayfinding impairments and the current study will also use a questionnaire to ask participants about their strategy use.

Overall, the authors concluded from their study that maze tasks distinguished TBI participants from a matched comparison group because of an impaired ability to form, utilise or remember cognitive maps. Instead they relied on a single (proximal) cue rather than the relationship between (distal) cues. Specifically the authors propose that using a proximal cue allowed participants to navigate using an egocentric frame of reference (person/body centred) and stimulus-response learning could occur (i.e. forming basic associations between the golden urn and the hidden platform with repeated exposure). Previous studies exploring the positioning of landmarks have shown that people demonstrate a preference for landmarks that act as beacons (Waller & Lippa, 2007), where the position of the landmark indicates the goal location and the correct route can be taken by walking towards the landmark (Chan et al., 2012). It is possible that Livingstone and Skelton's participants may have successfully located the platform in the single object and ambiguous mazes by walking towards the golden urn and walked over the hidden platform because of its proximity to the object which served as a beacon, rather than making an association between the urn and the location of the platform.

Therefore, the virtual environment in the present study will not position landmarks as beacons i.e. that the correct turning at the choice point can simply be made by heading directly towards a landmark. As previously described in Chapter 6, the position of the landmarks and the correct turning (left, right or straight on) were randomly allocated. Proximal landmarks have been positioned randomly on one of the four corners at each choice point. Each landmark is positioned directly on the corner between two streets so that using it as a beacon is not possible and walking towards it would send the participant directly in to a building, rather than along the correct route. Distal landmarks have been positioned randomly at one of four positions in the field of view of the participants when they approach the choice point (see Chapter 6 for details). Again, using the landmark as a beacon and walking directly towards it would send the participant into a building and not along the correct route. Therefore, the present study hopes to address the methodological concern raised here that Livingstone and Skelton's participants may have used the golden urn as a beacon, by positioning landmarks in the virtual environment so that they do not serve as beacons.

A further point regarding Livingstone and Skelton's study is that the trial order was not counterbalanced in any of the studies and participants experienced the same tests in the same order across studies. Participants completed the allocentric trial, followed by the egocentric trial and finally, the trial where either strategy could be used. The order of these conditions should have been counterbalanced to avoid order effects and therefore, the current study will address this by counterbalancing the order of the distal and proximal conditions.

Overall, the virtual MWM task does indicate that people with TBI may be able to learn an association between a proximal landmark and movement in space. However, the virtual MWM arena is designed to explore place learning (locate the place of the hidden platform) where, as long as the navigator has learned the spatial relationships between landmarks/objects in the environment, they can find the location, even if it is not visible.

Although navigating to a place is an important part of real world wayfinding, journeys are usually made up of a series of turnings and landmarks encountered along the route. In route learning, the aim of the navigator is to learn and remember a specific path and it is possible to do this without using an allocentric strategy (i.e. by learning the correct directions at choice points along the route) and this may not necessarily involve learning the spatial relationships between the object itself and other cues. In this case, it may be possible to follow a route, without necessarily forming an allocentric representation or cognitive map of the surrounding environment (Trullier et al., 2007). This may be more of an appropriate starting point for people with wayfinding difficulties as improvements in route learning, rather than place learning have also been successfully demonstrated in individuals who have had a brain injury (Bouwmeester, van de Wege, Haaxma & Snoek, 2014) and have been successfully used VR in the learning process (Brooks et al, 1999), therefore, the current study will focus on route learning.

7.1.4 The use of proximal and distal landmarks for virtual route learning

As discussed in Chapters 5 and 6, the virtual environment for this study was designed to build upon the work of Livingstone, Skelton and colleagues, by making the same landmark distinction between proximal and distal cues (Ruddle et al., 2011). Landmarks are frequently reported as common and instinctively used navigational cues by people with ABI (Lemoncello et al., 2010a) and have been used successfully in a small number of route learning case studies (Antonakos, 2004; Rainville et al., 2005. See Chapter 8). Despite their use in studies of place learning experiments described above, relatively little is known about how these types of landmarks are used in route learning, which is an everyday task that is necessary for independent travel. As discussed in Chapter 4, there is a lack of ecologically valid tools for assessment of wayfinding difficulties and rehabilitation tends to focus on goal driven, personally relevant real world tasks (e.g. learning a route to the local shops or to a place of work). The exploration of proximal and distal landmark cues may therefore offer an insight into route learning impairments and a greater understanding of how these cues are used after TBI. Therefore, the present study will use this method to explore route learning after TBI.

Route learning involves learning and remembering a sequence of pre-determined turns and may be viewed as a sequence of stimulus-response associations (Trullier et al., & Meyer, 1997), which involve recognition of the current location (e.g. recognising a landmark) and making a decision as to which way to turn (Waller & Lippa, 2007). These stimulus-response associations can be encoded egocentrically and are therefore, encoded in the direction the route is travelled (e.g.

turn right at the post box). In order to elucidate the anatomical location of this type of learning, a virtual reality study by Hartley et al. (2003), using fMRI techniques compared route learning performance across three conditions: Following a visible trail to a location; following a learned route to a location; and a place learning trial involving free exploration to find the location. Ceiling effects in the visible trail following condition made statistical comparisons invalid but comparisons between the route learning and place learning trials revealed that accurate navigators (those who reached their target locations) showed activation in the caudate during route learning trials and the hippocampus during place learning. Interestingly, poorer navigators did not show this pattern and the authors suggest that this supports the concept demonstrated in the MWM, that the hippocampus is involved in place learning and developing a cognitive map. However, these results should be interpreted with some caution as the tasks did overlap somewhat. Specifically, the route learning condition in the study also involved elements of active exploration and place learning as, during the learning phases of the route learning trial, participants had to learn the route by actively searching the environment for a target location (a picture) and walking towards it. Furthermore, the type of landmark was not controlled (i.e. there was a mixture of proximal and distal landmarks), so it was not possible to know the effect of landmark type. Therefore, the present study will seek to clarify the role of these types of landmarks during route learning by using only type of landmark in each condition.

In one of the few studies which has begun to explore the use of proximal and distal landmarks in neurologically intact individuals, Steck and Mallot (2000) used a virtual reality ‘Hexatown’ to explore the use of proximal and distal landmarks in two route learning tasks. Road junctions in the town contained everyday proximal landmarks (e.g. a phonebox) and distal landmarks surrounded the town (e.g. a television tower). Participants were first given training in the environment and then had to learn a specified route between a virtual home and an office. Once participants has successfully learned the route, they completed two different experimental tasks. In the first of these, participants were required to repeat the learned route from home to office as they had done in the learning trials, but whilst the distal landmarks remained stable, the proximal landmarks had been moved 180 degrees. This presented participants with conflicting cues (i.e. the landmarks were in different places) and their choice of turning at each decision point (i.e. right or left) would indicate which landmark they were using to guide their route choice. The results showed mixed findings, as some participants made their route choices based on exclusively proximal landmarks, some used only distal landmarks, whilst others used a mixture of the two.

The second stage used the same route learning task (using a second, different route) but instead of rotating landmarks, the landmarks were selectively obscured by using different lighting conditions (day, night and dawn). The day condition contained both visible proximal and distal landmarks; in the night condition only proximal landmarks were visible; and in the dawn condition only distal landmarks were visible. The purpose of performing the same route learning task under these conditions was to see whether the same participants demonstrated the same preference for proximal or distal landmarks as they had done previously in the cue conflict condition.

The results of this second route learning trial demonstrated that although some participants had shown a preference for one landmark type in the cue conflict condition, they were able to perform well in the second condition when only the opposite landmark type was visible. This indicates that, despite their initial preference, both types of landmark and the directional information associated with them was encoded. Overall participants performed better on the route learning task when both proximal and distal landmarks were available, indicating that better performance on the final task was related to the presence of both proximal and distal landmarks together.

However, it is also important to consider how a route is taught in a route learning task. The participants in Steck and Mallot's (2000) study were required to actively explore and walk around the environment in the training phase, in order to find the shortest route between home and office. When the correct route choice was made and a target location, which formed part of the specified route was reached, a message was displayed on screen to inform participants. This continued until the route was learned. Participants were also required to learn the route forwards (home to office) and backwards (office to home). These tasks may draw upon very different skills to those involved in a one way route learning task, where one is required to learn a series of straight on/right/left turns in order to follow a pre-specified route in one direction. When retracing a route which has been learned in one direction, the turnings will be approached from a different direction and in a different order. Therefore, the task requires adequate mental transformation. For example, once this route has been learned, being asked to retrace the same route in reverse from memory, is an allocentric task which. Completing a route in reverse means that, for example, one can no longer remember to turn right at the post box but must, in fact, use an allocentric reference frame to understand the nature of the relations between objects from an allocentric perspective, which may also engage different neuronal circuits (Burgess & Kingdom, 2008). This type of route retracing task has recently been investigated in relation to cognitive ageing (Wiener et al., 2012). The study found that older adults were more impaired when retracing a learned route from the opposite direction, when compared to younger adults. The authors suggest that this may reflect a shift from allocentric to egocentric strategies as a consequence of hippocampal degeneration. This has similar implications for brain injury, whereby hippocampal function may be affected (Atkins, 2011; Kotapka et al., 1992; Mañeru et al., 2005; Tate & Bigler, 2000; Tomaiuolo, et al, 2004) and therefore, it is important to understand how proximal and distal landmarks are used on a route learning task first, before other parts of the task are manipulated. However, one drawback in the study is that the active exploration of an environment has been found to encourage allocentric processing in spatial tasks (Wallet et al., 2013) and therefore, may prime participants to select a distal landmark strategy in response to the allocentric nature of the task.

To date, only one study has explored the use of proximal and distal landmarks on a route learning task that does not include an element of place learning or active exploration in the training phase (Ruddle et al., 2011). In this study, participants (N = 56) were assigned to one of four landmark groups during a route learning task in a virtual market as shown in Figure 7.2; a) no landmarks, b) proximal only, c) distal only or d) both proximal and distal landmarks. As can be seen in Figure 7.2, the landmarks (pictures of recognisable objects) were placed in fixed positions. The proximal landmarks were placed at intersections and the distal landmarks were placed on the walls.

Participants completed i) a practice task of 5 forward and 5 return journeys led initially by the researcher (e.g. A to B, then return to A) to practise the controls; ii) four forward and four return journeys along the practise route guided by arrows (the arrows were only provided on the first outward journey) but participants were prevented from getting lost by a cross on the computer screen if the incorrect route choice was made; iii) four forward and four return journeys along the test route guided by arrows on the first outward journey only, mistakes being corrected by a cross on the computer screen; and finally iv) post test questions on strategy use, photographic landmark recognition and a sketch map task.

Overall the results of the study showed that participants made significantly fewer errors in the proximal landmark condition, compared to the distal condition, as trials progressed. The authors suggest that the reduction in errors over trials by the proximal group supports the use of proximal landmarks in learning a specific route, rather than learning the overall layout of the environment. Results from the proximal landmark condition also resulted in a reduction in a particular type of error, namely participants carried on walking straight ahead, when they should have turned to the left or right. This type of error is line with research which suggests that when people are unsure of which way to turn, they tend to continue straight ahead, sometimes referred to as the “when in doubt follow your nose” strategy (Meilinger, Frankenstein & Bülthoff, 2014, p. 1).

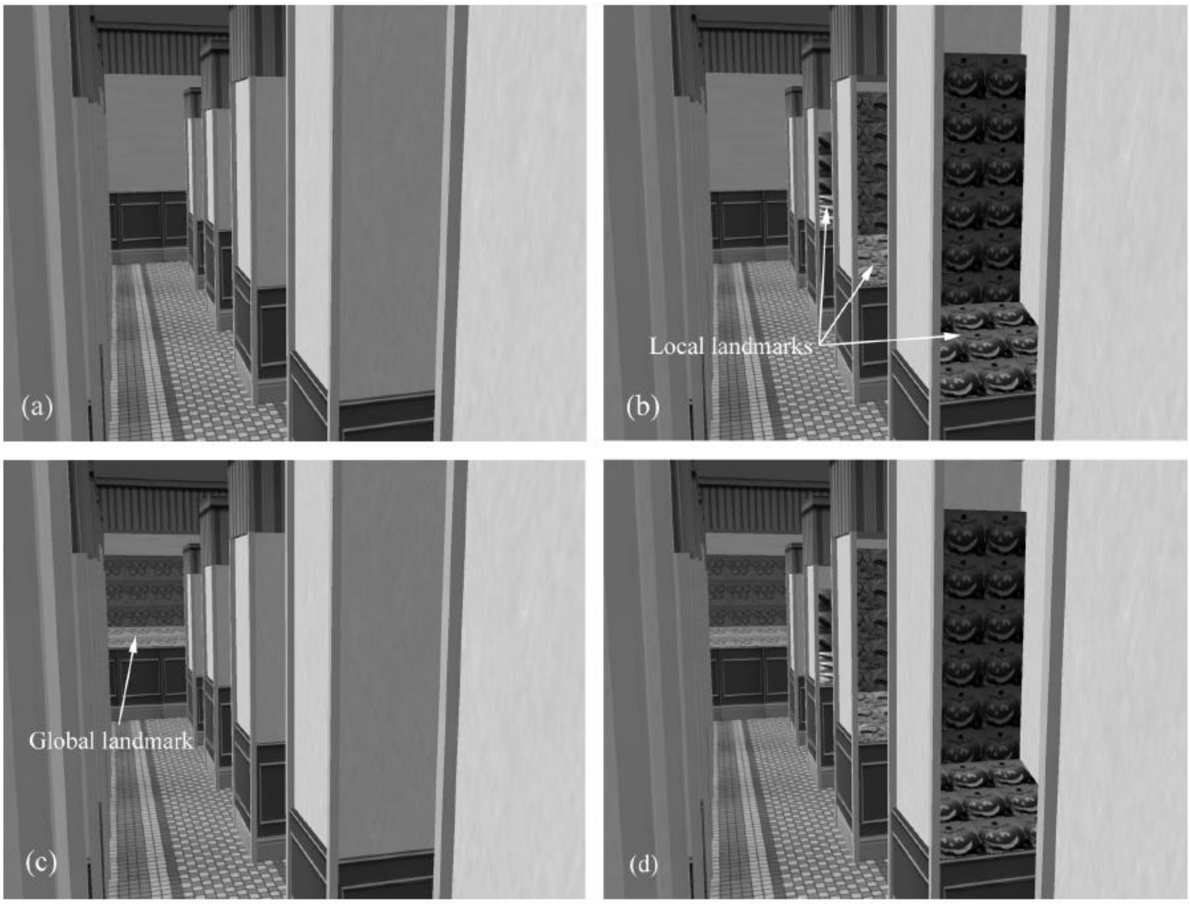

Figure 7.2: *The global and distal landmarks used in the route learning study by Ruddle et al (2011, p690) depicting a) no landmarks, b) proximal only, c) distal only or d) both proximal and distal landmarks.*

The results also demonstrated that when both proximal and distal landmarks were available to participants, more errors were made in the return condition when the route was retraced from the opposite direction. This may have been because the guided outward journey allowed participants to learn the route by forming stimulus-response associations between proximal landmarks and the correct turning. However, the return journey could no longer be solved using the same stimulus-response associations (i.e. turning right at a particular landmark on the outbound journey may have been a learned response but turning right at the same landmark on the return journey would result in an error).

The sketch map drawing task showed no significant differences between the proximal and distal landmark conditions. The correlational results indicated that the sketch maps did correlate positively with overall route learning performance. It is not possible to know why this result was found but it may indicate that better navigators are those who are able to build up a cognitive map of their environment.

Although the study is the first to offer an insight into a purely route learning (rather than place learning task), methodological choices in the virtual environment may have confounded results. The distal landmarks were positioned at the end of the path (see figure 7.2) but if participants moved along the path and passed this landmark, it would become proximal. This makes it difficult to draw firm conclusions from the results as to how proximal or distal landmarks are used in isolation because, in effect, the distal condition was not purely distal. Therefore, the current study will seek to address this issue by ensuring that the proximal and distal landmark conditions do not contain landmarks which could be viewed as both proximal or distal (see Chapter 6).

7.1.5 Summary

The current study will focus on a route learning task, as this is an everyday task which has the potential to improve independence and participation after brain injury and route learning has been explored in a small number of case studies which suggest it can be improved after brain injury (Bouwmeester et al., 2014; Ciaramelli , 2008; Newbigging & Laskey, 1996. See Chapter 8 for further details). When looking at the potential to inform rehabilitation, a focussed task such as route learning can also work with the goals of the patient (e.g. learn the route to the local shop or to a work placement) and can be clearly broken down in stages during the rehabilitation process using stimulus-response learning pairs (e.g. turn right at the post box). There is also an emerging body of research that supports the transfer of wayfinding skills from the virtual to the real world (Brookes et al., 1999; Darken & Banker, 2008; Farell et al., 2003; Sorita et al., 2012; Wallet et al., 2009) and the equivalence across virtual and real world environments (Lloyd et al, 2009a). Therefore, the current study has a taken another step towards improving ecological validity in the assessment of route learning by creating a task which reflects a real world scenario (an urban street environment), rather than a pencil and paper-based assessment (Parsons, 2011).

Overall, a complex task such as wayfinding will inevitably utilise a number of different cognitive skills and processes but research using the MWM and variations of it, have recognised two important frames of spatial reference, which can be identified by the way in which landmarks can be used and the brain regions associated with them. Egocentric strategies are based on the individual and allow the navigator to form stimulus-response associations with proximal or distal cues along a route and make body-centred, directional responses (e.g. turn right). Allocentric strategies can allow the navigator to form a cognitive map of the environment, which contains information about the layout of the environment and the relationship between the objects or landmarks in it. Allocentric strategies are believed to rely on distal landmarks for orientation and proximal landmarks for place recognition (Doeller &

Burgess, 2008; Jacobs et al., 2003; Livingstone & Skelton, 2007) but relatively few studies have explored the effect of proximal and distal landmarks on route learning.

In their first experiment, Steck and Mallot (2000) found that neurologically intact participants demonstrated different preferences for proximal landmarks, distal landmarks or a mixture of the two. In their second experiment, they found that participants who had demonstrated a preference for one type of landmark were still able to use the opposite landmarks type but better route learning performance was demonstrated when both types of landmarks were available. Whereas Ruddle et al., (2011) reported that participants in their study made significantly fewer errors in the proximal landmark condition, compared to the distal condition. In a further study, Livingstone and Skelton (2007) reported that participants with TBI performed significantly worse than controls on a place learning task when only distal landmark cues were available but were not impaired on the task when a proximal cue was present. The authors suggest that this is selective impairment in TBI, whereby, in the absence of proximal cues, participants are unable to use distal cues to help them form, remember or use a cognitive maps of their environment to navigate.

The current study builds upon the work of Livingstone and Skelton's (2007) place learning task, by exploring the use of proximal and distal landmarks on a route learning task in participants with a TBI. Specifically, it will seek to determine whether the difficulties using distal landmarks are observed on a route learning task. It is hoped that a greater understanding of the mechanisms involved in learning a route using proximal and distal landmarks, using a more ecologically valid task will allow practical recommendations to be made for the rehabilitation of route learning impairments after TBI. Methodological differences, which may have accounted for some of the mixed findings described above will also be addressed. The current study will not place landmarks as beacons, so that the task cannot be solved by simply heading towards a cue. Furthermore, landmarks will be positioned so that they cannot serve as both proximal and distal in the same condition and the order of the conditions will be counterbalanced, to remove order effects.

The current study will also explore navigational strategies in the two conditions, as these were only explored in one of the studies reviewed in this Chapter (Livingstone & Skelton, 2007) but the results of the self-report questionnaire suggest that TBI participants may have been able to identify the strategy they used to locate the platform. Given that increased awareness of intact skills/strategies has been associated with better rehabilitation outcomes (see Ownsworth & Clare, 2006 for a review), it is of particular interest to explore whether these results may extend from a place learning to a route learning study, which may have the potential to benefit rehabilitation.

Furthermore, in the absence of relevant imaging results, neuropsychological tests of visual and spatial memory will also be used in the current study with the TBI participants for demographic purposes, to provide detail about the severity of cognitive problems in the TBI group (further details of the tests are provided below). Only one study described above explored the relationship between neuropsychological tests and performance on a virtual wayfinding task (Livingstone and Skelton, 2007) and the authors report that performance on the tasks did not correlate well with the standardised tests. However, one of the aims of this research is to contribute to our understanding of the way in which landmarks are used during route learning and to use these findings to inform rehabilitation where appropriate. Therefore, it is important to understand the relationship between standardised neuropsychological test scores which are already used in rehabilitation and route learning performance, in order to inform rehabilitation strategies.

7.1.6 Aim

The main aim of the study was to explore the impact of landmark type (proximal or distal landmarks) on VR route learning in people with TBI, compared to a neurologically intact comparison group. Route learning performance was measured by the number of correct turns when repeating a route from memory. In order to measure explicit knowledge of the route, landmark recall and the spontaneous drawing of a sketch map of the route were recorded. A further aim was to look at the impact of landmark type (proximal or distal landmarks) on subjective reporting of navigational strategies in participants with TBI compared to neurologically intact controls. A final aim was to explore the correlation between route learning performance and neuropsychological test results, to examine whether deficits in spatial memory were related to route learning performance. Further details of the specific measures and the rationale for their inclusion in the study are presented in the Apparatus and Materials section below (Section 7.2.4).

Specifically, the study aimed to explore the difference between both i) proximal versus distal landmark-based conditions and ii) TBI participants versus neurologically intact comparison group using the following research questions:

1. Is there a difference between conditions or groups in performance on a virtual route learning task?

2. Is there a difference between conditions or groups on sketch map drawing?

3. Is there a difference between conditions or groups on the number of landmarks recalled?

4. Is there a difference between conditions or groups in performance on self-reported navigational strategies on a virtual route learning task?

5. Is there a relationship between neuropsychological test performance and route learning performance?

7.2 Method

7.2.1 Design

A mixed factorial design was employed in the study. The between factor was group (TBI or neurologically intact controls) and the within factor was the landmark condition (proximal or distal). Participants completed both within group conditions and the route order was counterbalanced to control for practice effects. Specifically, half of the participants completed the proximal route and half of the participants competed the distal route first. The routes were completed on two separate sessions, approximately one week apart to ensure that there was no interference i.e. that material learned about one route was not carried over to the second route.

7.2.2 Participants

A total of 16 participants with TBI took part in the study; 14 males and two females. Participants were recruited from two regional branches of Headway and all were attending day services at the centres. Inclusion criteria were a TBI at least 6 months prior to commencing the study, older than 18 years at the time of injury and some residual difficulties with everyday memory as judged by the key workers, in consultation with their client records. Exclusion criteria were marked comprehension or physical difficulties that would make it difficult to operate the joystick or complete the task.

A convenience sample of 16 neurologically intact comparison participants also took part in the study; 14 males and two females. Inclusion criteria were aged 18 years or over at the time of the study. Exclusion criteria were physical difficulties which would make it difficult for someone to operate the joystick and no history of an acquired or traumatic brain as judged by participants in response to the questions “have you ever suffered any kind of brain injury?” and “have you ever suffered a blow to the head that has rendered you unconscious for more than 15 minutes?”.

7.2.3 Power analysis

An a priori precision analysis was conducted using G*power (Faul et al., 2007) for repeated measures ANOVA with a between and within subjects interaction with alpha set at .05. Following Cohen’s (1998) conventions for describing effect size, a moderate effect size (.25) would require a total sample size of 34 to achieve power of .8 (assuming a correlation of .5 between the repeated measures). According to

Borenstein, Rothstein, Cohen, Schoefeld, Berlin et al. (2001) the decision about appropriate effect size should consider the context of the study and, as we wish to establish clinically meaningful implications for the purpose of rehabilitation, one would not wish to consider anything smaller than a moderate effect size.

7.2.4 Apparatus and Materials

All participants completed a pre-test demographics questionnaire, two landmark conditions in VR, two post-test map drawing tasks, two self-report navigational strategy questionnaires and a virtual presence question. Participants with TBI also completed a landmark identification screening test and three memory assessments prior to the task. These tests was administered to TBI participants only for demographic purposes to provide detail about the severity of cognitive problems in this group.

7.2.4.1 Demographic Information

Demographic information included age, gender, ethnicity and highest level of educational attainment. Participants with TBI were also asked to provide details on the type of injury and the time post-injury. Descriptive data can be found below in Tables 7.1 and 7.2 below.

7.2.4.2 Famous landmark recognition

This test was designed to screen participants for difficulties recognising familiar landmarks, as the ability to recognise landmarks is essential for route learning in the current study and in the real world. In a similar procedure to first part of the test used by McCarthy, Evans and Hodges (1996), participants were shown photographs of five famous landmarks and asked to verbally recall the name of each. Famous landmarks were used to screen for landmark agnosia which can impair the recognition of landmarks which provide information about direction/orientation (rather than just objects) and would make it difficult for participants to complete the task (see Aguirre & D'Esposito, 1999 for a review) One point was allocated for a correctly recalled landmark. The landmarks used were Big Ben, the Eiffel Tower, the Leaning Tower of Pisa, the Statue of Liberty and Stonehenge.

7.2.4.3 Adult Memory and Information Processing Battery List Learning subtest (Coughlan & Hollows, 1985)

The Adult Memory and Information Processing Battery (AMPIB) list learning task assesses verbal learning over a series of verbal recall trials. The researcher reads aloud a list of 15 words and the participant recalls as many words from the list as possible. This is repeated over five trials and on the sixth trial, a distractor list of 15 new items is presented for verbal recall. On the final trial, no word list is presented and the participant is asked to recall as many words from the original list as possible. The raw scores are age-scaled and converted to z-scores. Reliability for the whole scale has been reported as .77 and reliability for the distractor trial as .73 (Coughlan, Hollows & Coughlin, 1985). This task was administered in order to provide an objective assessment of TBI participants' memory difficulties. Lloyd (2007) showed that difficulties with verbal memory as measured on this task, correlated positively with poor route learning performance in participants with a brain injury.

7.2.4.4 Wechsler Memory Scale IV Spatial Addition subtest (Wechsler, 2009)

This test was administered to TBI participants only. The Spatial Addition subtest of the Wechsler Memory Scale (WMS) is designed to measure visual-spatial working memory. In particular, this task tests spatial location memory in a free recall format and was included because the spatial component of the visuo-spatial sketchpad (VSSP) has been shown to be important for route learning (Meilinger et al., 2008). The researcher shows the participant a stimulus booklet containing a pattern of red and blue circles on a grid. The researcher removes the stimuli from view and the participant is required to replicate the pattern of circles on their own copy of the grid from memory. The number of circles increases sequentially and the test is stopped if the participant fails to complete the trial after three consecutive attempts. Scoring for the test is allocated as follows: 1 point = correct recall of all circles in the correct position on the grid, 0 points = the correct circles are not recalled or more than the correct symbols are recalled. The raw scores are age-scaled and converted to index scores. Reliability for the scale is reported as .91 and test re-test is .74 (Wechsler, 2009)

7.2.4.5 Wechsler Memory Scale IV Symbol Span subtest (Wechsler, 2009)

This test was administered to TBI participants only. The Symbol Span subtest of the WMS was included in order to measure the visual and spatial components of the VSSP in working memory as Mallot and Gillner (2000) suggest, route learning requires the storing of a series of visual ‘snap shots’ along a route using working memory. The task tests the recall of visual detail and the sequences of images using recognition memory format. The researcher shows the participant a stimulus booklet containing a series of abstract symbols. The researcher removes the stimuli from view and the participant is required to point to the correct symbols in the order they were originally presented. The number of symbols increases sequentially and the test is stopped if the participant fails to complete the trial after three consecutive attempts. Scoring for the test is allocated as follows: 2 points = correct recall of all symbols in the correct order, 1 point = correct symbols in the incorrect order, 0 points = the correct symbols are not recalled or more than the correct symbols are recalled. The raw scores are age-scaled and converted to index scores. Reliability of the scale is reported as .88 and test re-test is .72 (Wechsler, 2009).

7.2.4.6 Navigational Strategy Questionnaire (all participants)

A navigational strategy questionnaire was used in the present study to explore which strategies or features of the virtual environment participants recalled using and whether these self-reported strategies were different between the proximal and distal landmark-based route learning conditions. The navigational strategy questionnaire used in the present was developed by Lloyd (2007) and all participants completed this questionnaire (Appendix I). It was used in the present study to compare self-reported strategy use in people with TBI with that of neurologically intact controls in the different landmark conditions. Participants rate their use of seven common wayfinding strategies on a 5-point Likert scale ranging from 1 = *not at all* to 5 = *almost totally.* The questionnaire showed adequate internal reliability in neurologically intact participants ($\alpha = .60$, $N = 70$).

7.2.4.7 Sketch Map Drawing (all participants)

The sketch map drawing task has been used in a number of wayfinding studies to assess whether participants are able to produce an external representation of a virtual route (Billighurst & Weghorst, 1995; Ruddle et al., 2011; Sorita et al., 2012; Tversky, 1993). After completing each virtual route, participants were given a grid which represented the layout of the streets in the virtual environment (see Appendix J). Participants were given the starting point on the grid but no other information was given. The researcher asked participants to “try and draw a map of the route you have just learned, just like you are drawing me a map to help me follow the route”.

Previous studies have demonstrated individual differences in freehand map drawing ability (Golledge, 1999; Murray & Spencer, 1979; Shah & Miyake, 2005), so the current study used a grid, rather than a blank piece of paper to compensate for these differences and to try to ensure the measure taken was of spatial knowledge, not of drawing ability. The objective scoring of subjective cognitive maps has been the subject of much debate and there is no generally accepted scoring technique (Billighurst & Weghorst, 1995). Therefore, the current study measured ‘map correctness’ (Schmelter, Jansen & Heil, 2013), which was a total score of the number of correct turnings drawn on the map (i.e. the number of correctly recalled turns out of a possible 15). In line with the procedure from previous route learning studies (Aginsky et al., 1997; Barrash et al., 1998; Sorita et al., 2012), a list of the correct turnings in number order was used to score each map. One point was assigned for drawing the correct turning at the appropriate point (e.g. the correct answer for choice point one was right, which scored one point, choice point two was a left turn, which scored one point). Participants were not penalised for turning in the wrong direction, as this may have resulted in the loss of a large amount of data. This is because the grid layout of the streets meant that after one wrong turning, a number of subsequent wrong turnings would have to be drawn in order to return to the correct destination. In line with the ‘Serial Position Effect’ (Ebbinghaus, 1964), people are more likely to recall the landmarks at the beginning and end of the route. If a participant deviated from the correct route in their sketch map, which resulted in the rest of the turnings being marked as incorrect, but did recall that, for example, the last two turnings were right and straight on, then this correct information may not have been reflected in the scores if an alternative method of scoring was used.

7.2.4.8 Landmark recall

Learning a route is generally considered to occur by encoding a series of stimulus-response associations, which may involve elements of both recognition (recognising where to turn) and recall (recalling associated directional information) but the role played by each is yet to be clarified (Chan et al, 2012; Steck and Mallot, 2000; Trullier et al., 1997; Waller & Lippa, 2007). Landmark recall was measured in the current study as emerging research suggests that people recall more landmarks in route learning tasks, when the landmarks are considered navigationally relevant (Chan et al., 2012; Janzen & van Turennout, 2004; Jansen-Osmann & Fuchs, 2006; Wegman & Janzen, 2011). Therefore, a measure of landmark recall may help us to understand whether the proximal and distal landmarks in the current study were perceived as navigationally relevant.

Landmark recall was chosen, rather than recognition as the route learning task did not require participants to recognise one landmark from an array of landmarks at each junction. However, participants were required to recall directional information at each choice point (i.e. which turning to take). As discussed in Chapter 6, one landmark was visible at each junction along the route. Findings from Livingstone and Skelton (2007) suggest that TBI participants were impaired on a navigational task when they were forced to rely on allocentric processing of the relationship between a set of cues but could navigate to a location when an association was learned with a proximal landmark. Therefore, if the current virtual environment had placed more than one landmark at each choice point, moving through a set of cues may have forced allocentric processing of a series of landmarks, which may reduce the advantage of using a single proximal landmark.

In the current study, participants were also asked to recall as many landmarks from the route as possible and the outcome was the number of correct landmarks recalled (maximum score for both was 15). For the purpose of this study, every landmark that was correctly recalled was awarded one mark and participants were not required to draw the landmark on the map.

7.2.4.9 Virtual Presence (all participants)

As described in Chapter 4, a feeling of being ‘present’ refers to the extent that the individual feels they are immersed in the virtual world (Slater & Usoh, 1993) and it is a “vital characteristic” (Rose, 1996, p. 5) of any virtual environment that may be used in rehabilitation. It has also been suggested that presence in a virtual environment incorporates the user’s ability to allocate their attention to the VE, rather than to the real world environment (Schaik, Turnbull, Wersch, & Drummond, 2004). Presence is often used as a measure of ecological validity in VR wayfinding studies (Livingstone & Skelton, 2007; Rose et al, 2001, Spiers & Maguire, 2008), as increased presence has been linked with increased transfer of training from the virtual to the real world (Keshner, 2004; Stanney & Salvendy, 1998) and with increased task performance in a virtual environment, compared to those feeling less present (Barfield, Hendrix & Bystrom, 1999).

In the current study, participants were asked a single question to gauge perceived presence in the virtual environment "To what extent do you feel present in the virtual environment right now?''. This was asked immediately after participants had completed each VR route. Answers are rated on a scale ranging from 0 (*not at all present*) to 100 (*totally present*). This single self-report measure has good test retest reliability (.81) in the same environment and in a different environment (.83). It also correlates with established measures of presence (Bouchard et al., 2005).

7.2.4.10 Virtual Environment

The virtual environments consisted of a series of identical residential streets in a grid pattern, Chapters 5 and 6 contains full details of the design process. The models used in the virtual environments were adapted from SketchUp warehouse and the Unity asset store and were developed in Google Sketchup Pro and Unity 3D. The routes were presented using a Dell Inspiron 15 (model 7537) laptop, with a 39.6cm LED backlit display, resolution 1920 x 1080. The laptop contained an NVidia GeForce GT 750M graphics card and participants navigated through the environment using a Logitech Extreme Pro joystick.

As described in the previous chapter, a practice route to ensure that participants were able to use the controls and understand the task and two equivalent routes were used in the study. Two experimental routes were used in the study and each route contained an equal number of turnings, junctions and landmarks. Route A contained 15 proximal landmarks and Route B contained 15 distal landmarks. The turnings (left, right and straight on) and position of landmarks were randomly allocated and the main outcome measure was the number of correct turns taken on each route on the VR recall trial.

7.2.5 Procedure

Staff at the rehabilitation day centres were briefed about the study and the inclusion and exclusion criteria. They were given the opportunity to ask questions and given information leaflets to distribute to potential participants. The researcher defined TBI to the staff as “an injury to the brain caused by a trauma to the head. There are many possible causes, including road traffic accidents, assaults, falls and accidents at home or at work” (Headway, 2009) This was confirmed by key workers at the centres (from their client records) and the researcher also asked key workers to confirm whether participants were suitable for inclusion in the study based on the exclusion/inclusion criteria. This was based on the client records and on the judgement of key workers, who worked very closely with the clients. Staff then approached potential participants who met the inclusion criteria and gave them an information leaflet. Participants who were interested in taking part made direct contact with the researcher who was frequently at the centres or indicated to a staff member that they would like to speak to the researcher about the study. The researcher then arranged a time explain the study in further detail and give participants the opportunity to ask questions. All participants were given a minimum of 24 hours to consider whether to participate in the study. Once agreed, appointments were made with participants at their day centre to begin the study. At the beginning of the first session, participants went through the information leaflet with the researcher and were given the opportunity to ask further questions. Participants wishing to proceed, read and signed the consent form (Appendix C) and then answered the demographic questions. After this, participants completed the landmark recognition and neuropsychological tests (the comparison group went straight on to the practice task).

Neurologically intact participants were recruited by distributing the participant information leaflets to Schools at the University of Birmingham. Comparison participants were matched to participants with TBI on an individual basis, on both age and educational qualification Individual matching was employed (Wacholder et al., 1992) and individual participants from the neurologically intact comparison group were matched to TBI participants based on being in the same age group (20-29 years, 30-39 years, 40-49 years, 50-59 years) and having the same level of education (see Table 7.1 below for qualification data). Potential participants were asked to contact the researcher directly via email or telephone. The researcher then arranged a convenient time to discuss the study directly with participants at the University. The researcher went through the information leaflet with the participants, they were given the opportunity to ask further questions and participants were given a minimum of 24 hours to consider whether to participate in the study. Participants wishing to proceed, read and signed the consent form (Appendix C) and then answered the demographic questions.

Next, all participants began the practice task. The laptop was positioned on a table at approximately an arm's length from the participant and the joystick was placed in front of the laptop, at a distance which did not obscure the screen. Participants were asked to confirm whether the position of the joystick was comfortable and adjustments were made by the researcher if necessary. The researcher demonstrated how to move forwards, backwards, left and right using the joystick and explained that the first task would give them the opportunity to practise using the joystick. Participants were instructed to use the joystick to navigate towards each arrow and to walk through the centre of it. A sound would indicate collection of the arrow and, after successfully picking up all four arrows, the participant moved onto the next task.

Participants were automatically positioned at the start of the route, which was indicated by a yellow start bar and given the task instructions (full instructions are reproduced in Appendix H). Participants were informed that their task was to follow the yellow arrows around a route and to try to remember the route. Participants were told that the arrows would not be there on the final test trial so using landmarks may help them learn the route. On the first lap of the route, participants were asked to call out the landmarks as soon as they saw them to ensure that they had seen them and that they were able to recognise which objects were landmarks. Participants completed three laps of the route following the arrows. On the fourth lap, the arrows disappeared and participants had to repeat the route from memory. The instructions were repeated to participants to ensure that they understood what they had to do. If a wrong turn was taken in any of the learning or test trials, the researcher positioned the participant back at the choice point and pointed out the correct direction. One point was allocated for a correct turning. All turnings were recorded by the researcher and the maximum score for each route was 15. After completing the test lap, participants answered the presence question and then moved away from the screen to complete the sketch map drawing task and strategy questionnaires. Participants repeated exactly the same procedure with the second landmark condition one week later.

7.2.6 Ethical Approval

Ethical approval was granted by the Birmingham, East, North and Solihull NHS Research Ethics Committee (see Appendix A).

7.3 Results

7.3.1 Demographic Information

A total of 32 participants took part in the study; 16 participants with TBI and 16 neurologically intact participants matched for age and educational attainment. An independent *t*-test suggested that there was no difference in the age of the groups $t(30)=-.03$ $p=.970$. Each group consisted of 14 males and two females. The mean age of the group with TBI was 44.94 years, (SD = 11.42). The mean age of the control group was 45.06 years (SD = 11.70). Participants' demographic information and results for the selected tests are summarised in Tables 7.1 to 7.2. The mean age at injury was 32.5 years (SD = 11.52). None of the neurologically intact comparison participants reported any kind of brain injury or experiencing a loss of consciousness for more than 15 minutes.

Table 7.1: *Frequency data for highest level of education*

Level of Education	TBI Group *n* = 16	Comparison Group *n* = 16
No qualifications	2	2
O'level, GCSE, NVQ	7	7
A/AS level, Advanced GNVQ	4	4
First degree	3	3
Higher degree (MA, MSc, PGCE, PhD)	0	0

Table 7.2: *Cause of injury and mean for participants with TBI (n = 16)*

Injury type	Frequency
Road traffic accident	8
Assault	5
Industrial accident	2
Fall	1

7.3.2 Neuropsychological Tests

As shown in Table 7.3, most participants with TBI scored within the impaired range for verbal learning and recall and in the average to low average range for visual working memory (spatial addition and symbol span). This table shows the age-corrected mean z scores and percentiles for the neuropsychological tests completed by the participants with TBI. Lower percentile cut-offs were set as 75 for high average, 25 for average, 9 for low average, 2 for well below average and below 2 as impaired. Using these cut-offs, 11 participants scored in the impaired range, two scored in the well below average range, one scored in the low average range, one scored in the average range and one scored in the high average range on the first 5 recall trails of the AMIPB list learning test. Fourteen participants scored in the impaired range on the delayed recall of the AMIPB list and two scored in the well below average range.

On spatial addition, 5 scored in the average range, 10 scored in the low average range and one in the well below average range. On symbol span, one scored in the high average range, 8 in the average range, two in the low average and four well below average.

Table 7.3: *Results of neuropsychological test for participants with TBI (n = 16)*

	Age Scaled Score		Percentile Rank		Range
Neuropsychological Test	*M*	*SD*	*M*	*SD*	
WMS Spatial Addition Score*	7.30	1.66	21.37	16.80	5-63
WMS Symbol Span Score*	8.13	2.92	32.94	26.74	4-13
AMIPB Learning (trials 1-5)**	-2.90	1.86	11.50	24.38	1-83
AMPIB Delayed Recall (trial 6)**	-3.17	.94	1.13	.39	1-3

*Note: * denotes age-scales t-scores, ** denotes age-scaled Wechsler subtest scores*

7.3.3 Route Learning Performance

All participants in the study were able to operate the joystick and successfully completed the practice route before completing both the experimental trials. All participants scored five out of five on the landmark recognition task. The mean score for the virtual presence question was 84.38 for the participants with TBI (*SD* = 13.52) and 64.38 (*SD = 11.53*) for the comparison group. The scores for the comparison group show that participants felt a good sense of subjective presence and these are judged to be 'good' in line with recent findings using this measure in neurologically intact individuals, which reported a mean score of 64.06 (*SD* = 22.6; Bouchard et al., 2005). However, there is no comparison for TBI participants. A *t*-test suggested that there was a significant difference between the groups with the people with TBI feeling more present in the virtual environment $t(30) = -4.5$, $p < .001$.

7.3.4 Research question 1: Is there a difference between conditions or groups in performance on a virtual route learning task?

In order to answer this question the data were first checked for outliers and missing scores and none were found. Secondly, the data were assessed for suitability for parametric analysis (Field, 2009). The Shapiro-Wilk test was conducted to explore for normality of distribution (which is recommended for detecting departures from normality in sample sizes from 10-50, Stevens, 2002). These showed deviations from normality for both proximal and distal data from the comparison participants (as the results were below .05). Data for participants in the TBI groups are above this threshold and as such, are within the parameters of normal distribution.

However, the *F*-test is very robust against non-normal distribution, especially in a fixed-effects model which means that the analysis can be conducted even if the data used violates some of the assumptions that underlie the use of the test, (Field, 2009, p. 155), especially in a fixed-effects model (used in this study) where all the steps under investigation are included in the analysis (Field, 2009, p. 732). Therefore, it was decided to carry out a mixed model ANOVA in which landmark type (proximal or distal) was represented as a within subject factor and group was represented as a between subjects factor (see Figure 7.3 and Table 7.4 for the descriptive data).

Table 7.4: *Number of correct turns in each condition for the TBI and comparison groups*

	TBI group (*n* = 16)			Comparison (*n* = 16)		
Landmark condition	*M*	*SD*	*Range*	*M*	*SD*	*Range*
Proximal	10.56	2.06	7-13	14.06	.93	12-15
Distal	5.63	2.13	2-9	13.50	.97	12-15

An initial ANOVA showed that Levene's test (which evaluates whether error variance is consistent across the factors) showed significant heteroscedasticity in both the proximal (Levene's $F(1,30) = 12.70$, $p = < .001$) and the distal (Levene's $F(1,30) = 11.91$, $p = .002$) conditions. The Box Cox test was used to establish whether a power transformation could control for the unequal variance and non-normality. This indicated that a power transformation of 2.4 would control this issue. This resulted in adequate control of the heteroscedasticity for both the proximal (Levene's $F(1,30) = 4.1$, $p = .060$) and the distal (Levene's $F1,30) = 3.6$, $p = .070$) conditions.

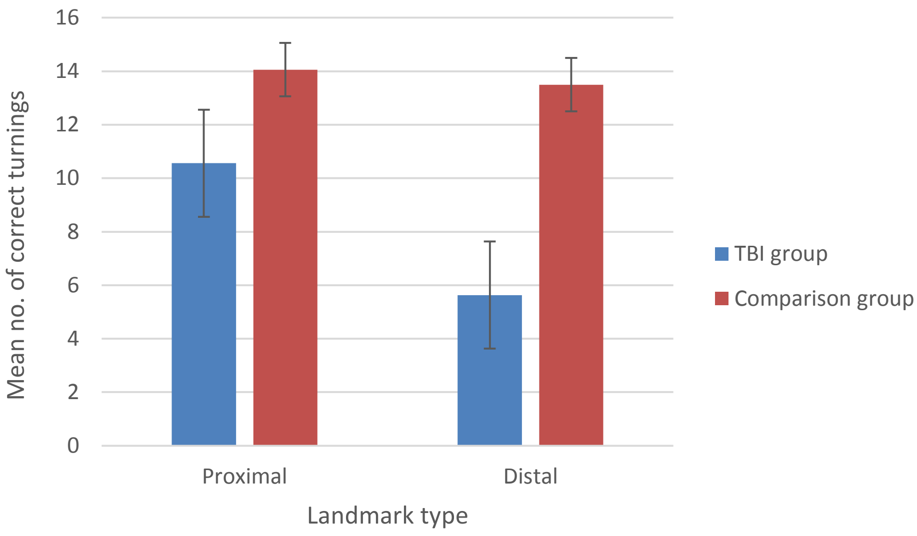

Figure 7.3: *Mean number of correct turns on the proximal and distal learning conditions for TBI and comparison groups, with error bars denoting the standard deviation (n = 16 in each condition)*

The power transformation of 2.4 did not, however, correct for non-normality of the data (see Table 7.5). It was decided therefore, that if the ANOVA returned a statistically significant interaction based on the transformed data, this should be verified using appropriate nonparametric tests, which would estimate the potential impact of non-normality on the ANOVA model.

Table 7.5: *Shapiro-Wilk test results in each condition for the TBI and comparison groups, with the transformation applied*

Route	TBI group (*n* = 16)		Comparison (*n* = 16)	
	Shapiro-Wilk W	*p*	*Shapiro-Wilk W*	*p*
Landmark (proximal)	.916(16)	.147	.851(16)	.014*
Landmark (distal)	.914(16)	.135	.883(16)	.043*

*Note: * p < .05 suggests the violation of the assumption of normality (Pallant, 2007)*

Based on the transformed data, results of the ANOVA showed that both of the main effects were statistically significant (landmark type $F(1,30) = 121.98$, $p < .001$; group $F1,30) = 135.00$, $p < .001$) and a significant interaction was observed between landmark type and group ($F1,30) = 47.07$, $p < .001$, $\eta^2 = .24$, $\eta_p^2=.61$). This large interaction accounted for approximately 24% of the variation in the data.

The Durbin-Watson statistic showed that there was no evidence of autocorrelation in the untransformed or the transformed data (for transformed data proximal = 1.91, distal = 1.66 respectively). Post hoc analysis using Tukeys HSD suggested that in participants with TBI there was a significant difference between proximal and distal landmarks ($p < .001$) but not in the comparison group ($p = .091$). There was also a significant difference between people with TBI and neurologically intact controls on proximal landmarks ($p < .001$) and also a significant difference between groups on distal landmarks ($p < .001$).

As these data were not normally distributed, this finding was replicated using non-parametric tests, using both within subjects variance estimates (Freidman X^2= 41.01, p <.001) and between subjects variance estimates (Kruskal-Wallis X^2=41.00, p

<.001). These findings confirmed the interaction effect found in the ANOVA. Overall, the results suggest that there was a significant main effect of group (TBI and comparison) and landmark condition (proximal and distal), with a significant interaction. Although the assumption of normality was violated for the control group, transforming the data resulted in leaving only one assumption violated. In addition, the nonparametric analysis, which is not predicated on any particular distribution (Gibbons & Chakraborti, 2011), adds credence to the findings of the ANOVA.

7.3.5 Research question 2: Is there a difference conditions or groups on map drawing?

The data were first checked for outliers and missing scores and none were found. Next the data were assessed for suitability for parametric analysis (Field, 2009, Pallant, 2007) beginning with the normality of distribution. The Shapiro-Wilk test showed deviations from normality for both proximal and distal data in TBI participants but not for the comparison group. Further exploration of the data using Levene's tests showed significant heteroscedasticity in both groups and the descriptive data in Table 7.6 shows that results from the TBI group were approaching floor effects.

Table 7.6: *Number of correct map drawings in each condition for the TBI and comparison groups*

Landmark condition	TBI group (*n* = 16)			Comparison (*n* = 16)		
	M	*SD*	*Range*	*M*	*SD*	*Range*
Proximal	2.63	1.09	1-5	5.63	2.66	1-12
Distal	1.63	.96	0-3	5.06	2.35	1-11

Therefore, given that the data for the map drawing in TBI participants violated more than one assumption for parametric analysis and the near floor effects in the map drawing of TBI participants may make parametric analysis unsuitable (Field, 2009, Tolmie, Muijs & McAteer, 2011), non-parametric statistics were applied Given the design of the study was both a within and between-subjects design, both within and between-subjects non parametric analyses were performed. Firstly in order to compare across all conditions and groups (controls proximal, controls distal, TBI proximal, TBI distal) a Friedman test was carried out and suggested a significant difference across groups (Freidman X^2= 37.85, p <.001). A Kruskal-Wallis test confirmed this finding (Kruskal-Wallis X^2 =32.46, p <.001). Further non-parametric analysis was therefore carried out in order to make pairwise comparisons.

A between group analysis using a Mann-Whitney test showed a significant difference between groups on proximal landmarks (U = 33, p <.001, r=-.64) and a significant difference between groups on distal landmarks (U = 19, p <.001, r = -.73). Finally, within group analyses using Wilcoxon-signed ranks tests showed that there was a significant difference in the control group between proximal (*Mdn* = 5) and distal (*Mdn* = 5) conditions (z =-1.96, p =.005, r =-.35) and there was a significant difference in the TBI group between proximal (*Mdn* = 2.5) and distal (*Mdn* = 2) conditions (z =-2.82, p =.005, r =.50).

In summary, results suggested that the TBI group recalled fewer landmarks than the control group in both the proximal and distal landmark conditions. Also, both the control group and the TBI group recalled fewer correct turns in the distal landmark condition. It should be noted that although the median scores for proximal and distal conditions were the same for the proximal group, the difference in the sum of ranks was large enough to be statistically significant. All effect sizes (*r)* except the difference between landmark conditions for the control group (which showed a medium effect size), were large according to Cohen's (1988) conventions.

7.3.6 Research question 3: Is there a difference between conditions or groups on the number of landmarks recalled?

In order to answer this question the data were first checked for outliers and missing scores and none were found. Secondly, the data were assessed for suitability for parametric analysis (Field, 2009; Pallant, 2007). The Shapiro-Wilk test was conducted to explore for normality of distribution (which is recommended for detecting departures from normality in sample sizes from 10-50, Stevens, 2002). These showed no deviations from normality for both proximal and distal data from the comparison participants (as the results were below .05). The Levene's test showed no significant heteroscedasticity in both the proximal (Levene's $F(1,30)$ = .03, p = < .861) and the distal (Levene's $F(1,30)$ = 1.66, p = .207) conditions, thus meeting a further criteria for parametric analysis. Finally, the Durbin-Watson statistic showed that there was no evidence of autocorrelation in the data (for proximal = 2.07 and distal = 2.05 respectively). Therefore, it was decided to carry out a two factor (group x landmark condition) within and between subjects ANOVA on the number of correctly recalled landmarks.

Table 7.7: *Number of correctly recalled landmarks in each condition for the TBI and comparison groups*

	TBI group (*n* = 16)			Comparison (*n* = 16)		
Landmark condition	*M*	*SD*	*Range*	*M*	*SD*	*Range*
Proximal	6.75	1.84		12.50	1.79	
Distal	2.50	7.79		8.06	1.53	

The results showed a significant main effect of group, $F(1,30) = 166.08$, $p = .00$, $\eta_p^2 = .85$, and landmark conditions, $F(1,30) = 157.59$, $p < .001$, $\eta_p^2 = .84$, . However, the interaction was not statistically significant, $F(1,30) = .07$, $p = .79$. The mean values for each level of the factors are presented in Table 7.6 and Figure 7.4. Post hoc analysis using Tukey's HSD suggested that: there was a significant difference in participants with TBI on proximal vs distal landmarks ($p < .001$), and also a significant difference for controls ($p < .001$). There was also a significant difference between people with TBI and controls on proximal landmarks ($p < .001$) and a significant difference between groups on distal landmarks ($p < .001$).

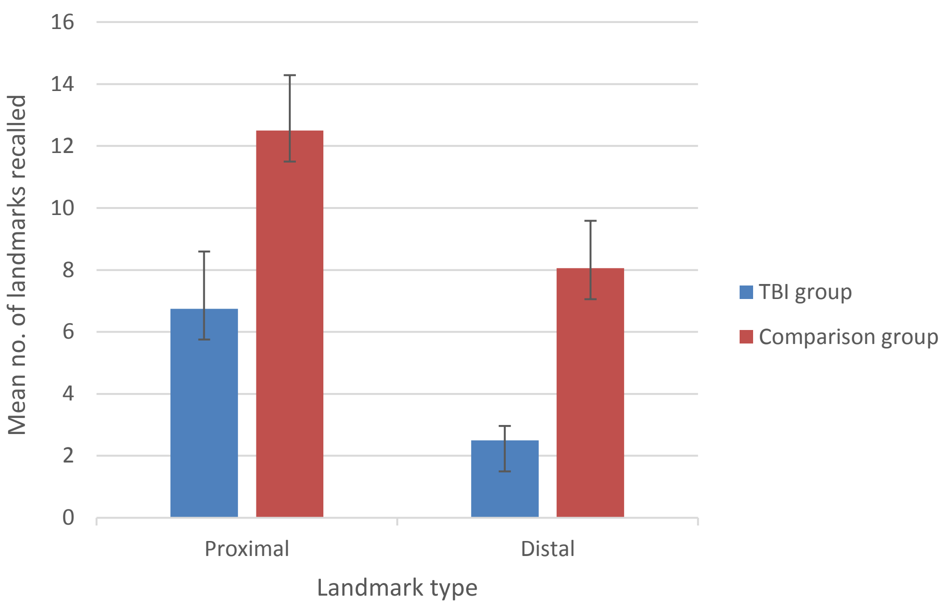

Figure 7.4 *Mean number of landmarks recalled in the proximal and distal conditions (n = 16 in each condition)*

7.3.7 Research question 4: Is there a difference between conditions or groups in performance on self-reported navigational strategies on a virtual route learning task?

In order to explore whether route type (proximal or distal) affected subjective reporting of navigational strategies in people with TBI compared with neurologically intact controls, each question on the navigational task was first assessed for normality (Field, 2009, Pallant, 2007). Firstly, the data were checked for missing data and outliers and none were found. Next the raw data were checked for normality, homogeneity of variance and skewness using the method previously described in this chapter (based on Field, 2009 and Pallant, 2007). The data did not meet the assumptions for parametric analysis and therefore, it was necessary to carry out non-parametric analysis to explore these aims. Two separate Kruskal-Wallis tests were conducted, the first to explore differences between people with TBI vs neurologically intact controls on each strategy question and the second to explore differences between proximal and distal conditions on each of the strategy questions.

For the difference between the comparison group and participants with TBI, three questions showed a significant difference. These were: '*I had no idea of the way so I guessed' (H(*1) = 6.29, <.001); '*I used buildings and other landmarks that I noticed along the way' (H(*1) =10.46, <.001; '*I followed my instincts, without knowing how I did it' (H(*1) = 46.09, <.001). Figures 7.5 5 to 7.7 show the scores for each of these questions broken down both by group and landmark strategy condition for ease of comparison.

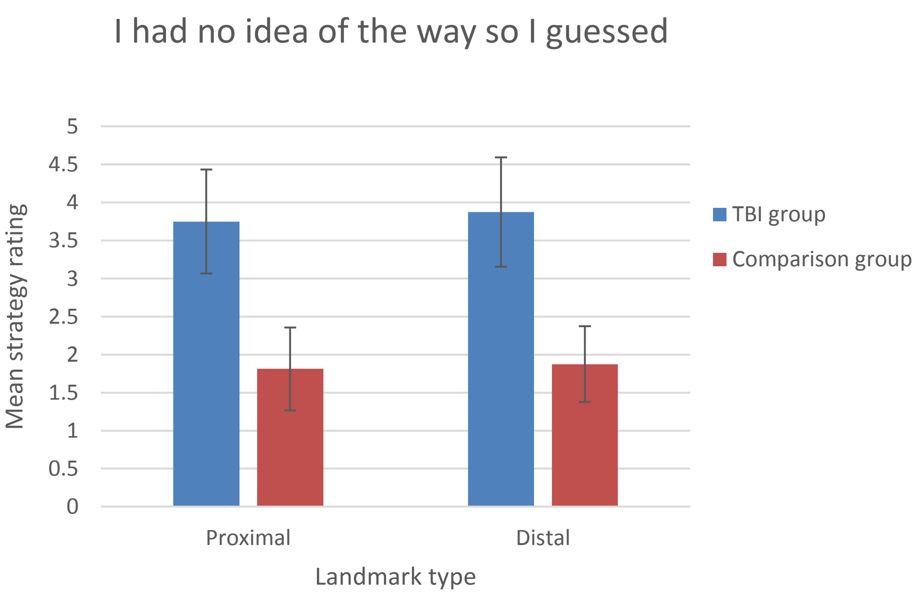

Figure 7.5: *Landmark condition by group for the question 'I had no idea of the way so I guessed' (significant effect for group).*

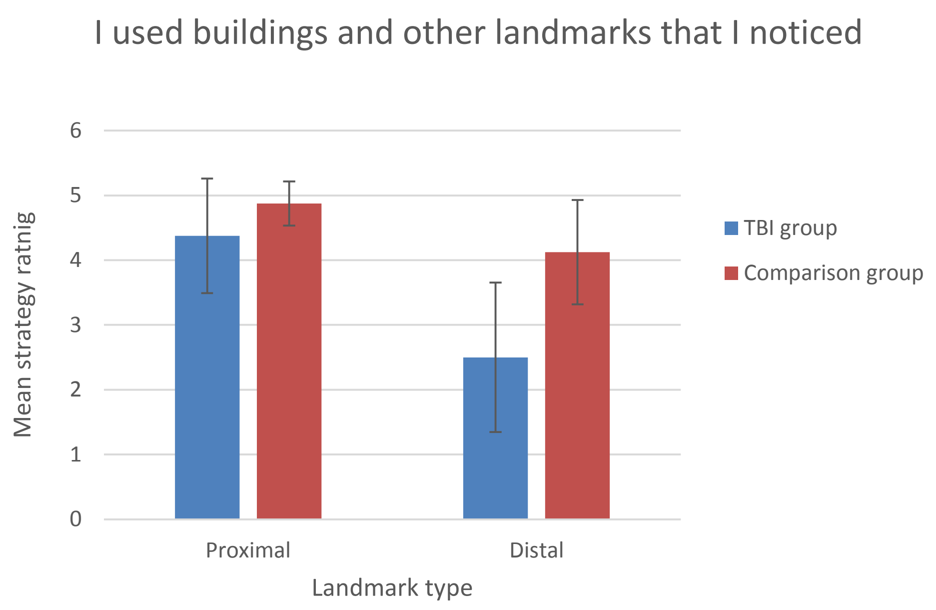

Figure 7.6: *Landmark condition by group for the question 'I used buildings and other landmarks that I noticed along the way' (significant effect for both group and landmark type)*

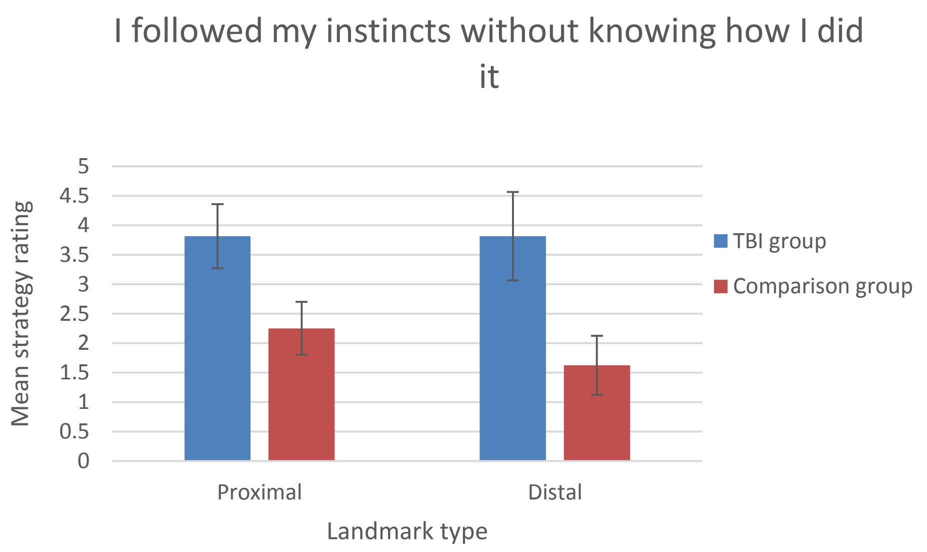

Figure 7.7: *Landmark condition by group for the question 'I followed my instincts, without knowing how I did it' (significant effect for group)*

For the difference between the proximal and distal landmark conditions, four questions showed a significant difference. These were: 'I tried to develop a 'birds-eye' map in my head' *(H(*1) =10.29, <.001); 'I used buildings and other landmarks that I noticed along the way' *(H(*1) =19.62, <.001; 'I used landmarks in the distance of my general direction to route myself' *(H(*1) = 46.36, <.001 and 'I used a verbal description of the route as I went along and remembered that' *(H(*1) =11.51, *p* <.001). Figures 7.8 to 7.10 show the scores for each question broken down both landmark strategy and group for ease of comparison.

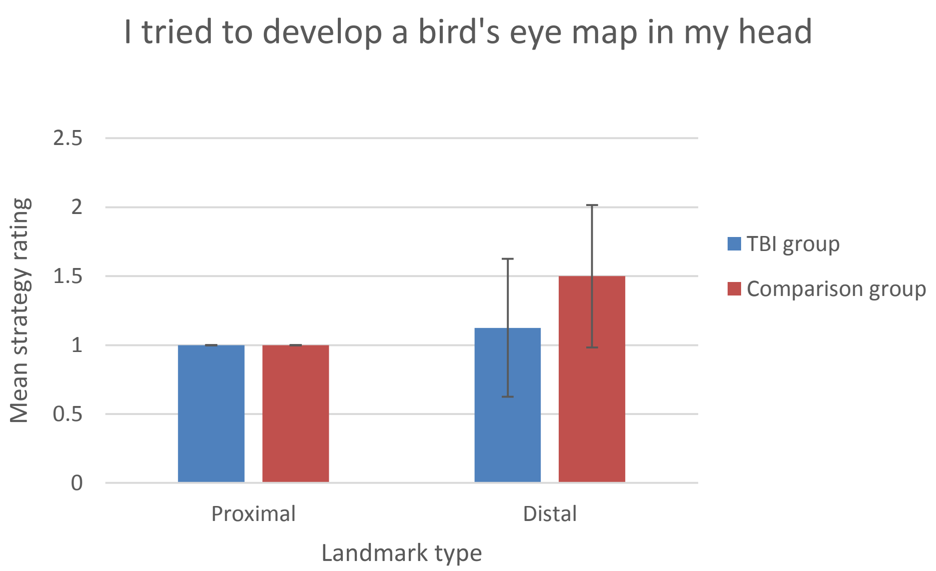

Figure 7.8: *Landmark condition by group for the question 'I tried to develop a 'birds-eye' map in my head' (significant effect for landmark type)*

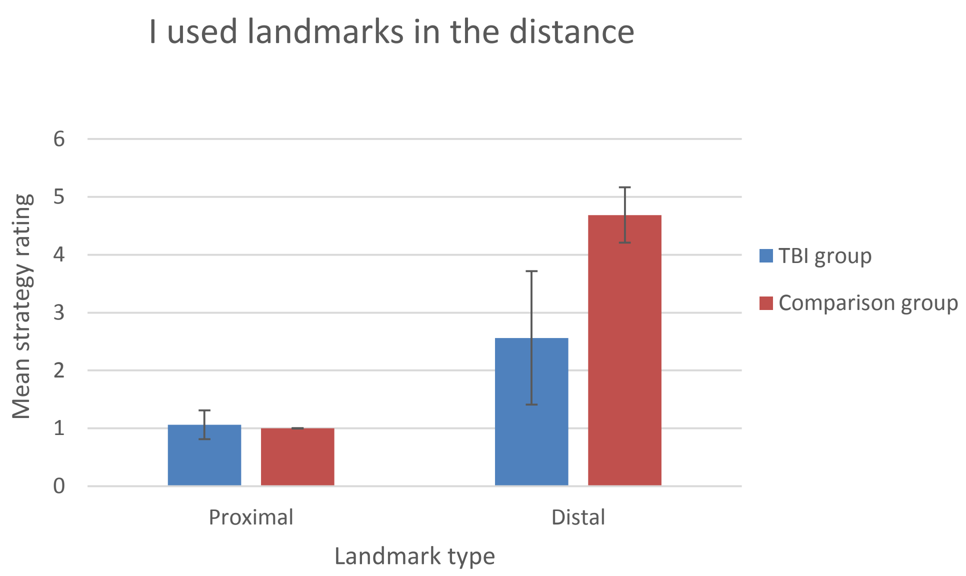

Figure 7.9: *Landmark condition by group for the question 'I used landmarks in the distance of my general direction to route myself' (significant effect for landmark type)*

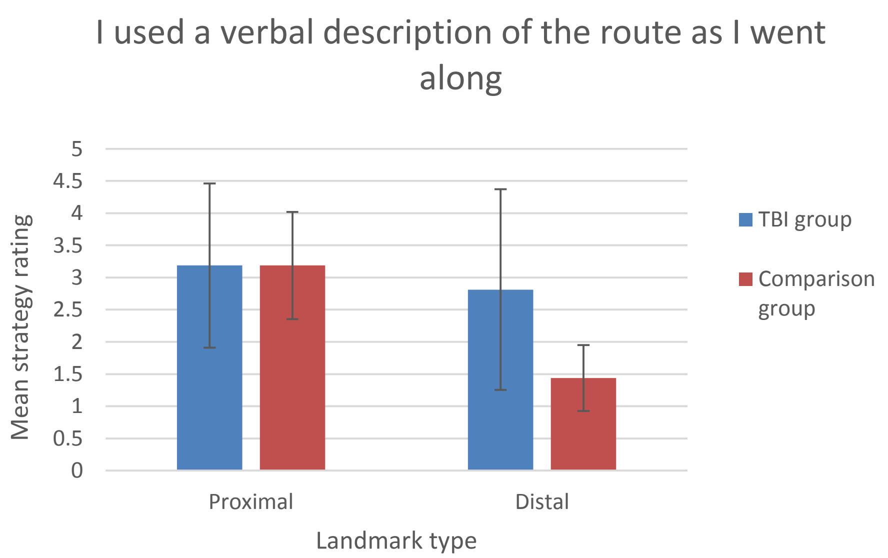

Figure 7.10: "*I used a verbal description of the route as I went along and remembered that"* (significant effect for landmark type)

7.3.8 Research question 5: Is there a relationship between neuropsychological test performance and route learning performance?

The data were first checked for missing items and outliers and none were found. The assumptions for the parametric correlational analysis were checked using the procedures in Field (2009) and Pallant (2007). The data were normally distributed but inspection of the scatterplots suggested that the data did not meet the assumptions for linearity and therefore, non-parametric Spearman's Rank Order correlation (rho) were conducted between the neuropsychological tests and route learning performance in each condition. Significant correlations were found between list learning and performance on the proximal route and symbol span and the distal route (see Table 7.8).

Table 7.8: *Correlations between neuropsychological tests (standard scores) and route learning performance (n = 16).*

Landmark condition	AMIPB (A1 – A5)		AMIPB (A6)		WMS Spatial Addition		WMS Symbol Span	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Proximal	.66*	.006	.48	.125	.13	.615	.52*	.008
Distal	.59	.054	.36	.240	.31	.268	.62*	.010

*Note: * Correlation is significant to p <.05*

7.4 Discussion

The present study investigated the use of proximal and distal landmark cues on a route learning task in a virtual environment. Differences between the landmark conditions (proximal and distal) were found consistently for people with TBI, with worse performance in the distal condition. Neurologically intact controls were disadvantaged in the distal condition on map drawing and landmark recall but not on VR route recall. Differences were also found between the two groups (TBI compared to a neurologically intact comparison group) with consistently better performance by the neurologically intact participants. Results also suggested that participants with TBI were proportionally more disadvantaged by the distal landmark condition on the VR route recall but not on the map drawing and landmark recall tasks. Results from the navigation questionnaires indicated that the use of buildings and landmarks as a strategy differed between the groups and also across experimental conditions. People with TBI tended to report guessing or the use of ‘instinct’ more than controls. As would be expected, people reported using a bird’s eye map and landmarks in the direction of travel more in the distal condition.

7.4.1 Scores on screening tasks and their relationship to test performance

Initial screening on the famous landmark tests shows that participants were able to recognise all five landmarks. This indicates that participants with TBI were able to recognise whole precepts of landmarks and did not demonstrate specific landmark agnosia, which would make it difficult for them to compete the task using landmarks (Brunsdon, Nickels & Coltheart, 2007). This suggests that any group differences observed were not related to a specific difficulty in recognising landmarks in people with TBI.

Although all participants' keyworkers had reported that they experienced everyday memory difficulties as part of the inclusion criteria for the study, two participants scored in the average or above average range in the immediate recall trials of the list learning task. However, both individuals scored below average on the delayed recall trial, suggesting that they may have had long term memory difficulties. A significant relationship was found between list learning (but not delayed recall of the list) and VR route recall for the proximal condition. Previous findings in relation to verbal memory and route learning have been inconsistent, with one study finding no association (Maguire, Spiers, Good, Hartley, Frackowiak et al., 2003) and two finding an association (Lloyd, 2007; Moffat, Zonderman & Resnick, 2001). The latter two studies used list learning tests whereas the former used story recall and the difference in findings may be related to congruity of tasks, with list learning being possibly more akin to route learning.

None of the participants was impaired on the visual working memory tests although several scored in the well below average range. Nevertheless, symbol span was correlated with VR route recall in both proximal and distal conditions. If, as Mallot and Gillner (2000) suggest, route learning requires the processing of a series of snapshots of the environment, this component of the VSSP may be an important skill to facilitate route learning and, as in the present sample, may be compromised to some degree in some people with TBI. However, some caution should be applied when interpretation results of these non-parametric correlations in a small sample. Increasing the sample size would therefore be a recommendation for future research.

7.4.2 Virtual Environment

The results of the presence questionnaire show that participants with TBI reported feeling more present in the virtual environment than the comparison group, although both groups scored relatively highly. As also noted by Livingstone & Skelton (2007), this suggests that the errors made in the test trials were not as a direct response to a feeling of ‘not really being there’ in the virtual environment. This is the first known study to demonstrate a difference in levels of presence between TBI and neurologically intact participants albeit, using a single question and from a small sample. It is important to note that a subjective sense of presence is difficult to capture (Schaik, Turnbull, Wersch, & Drummond, 2004) so the result of a single question should be interpreted with caution. However, a recent study using a virtual wayfinding task reported that both attention and self-awareness may be linked to a sense of presence i.e. reduced self-awareness in the real world may increase a feeling of presence in the virtual world (Clemente, Rodríguez, Rey & Alcañiz, 2014). Therefore, it may have been possible that TBI participants were attending to the stimuli or the task more than the comparison participants but at present, these findings are speculative as there is a lack of clear framework for conceptualising the experience of presence (Stanney, 2002). Previous research to date has reported that higher reported levels of presence have been shown to increase task performance (Loomis & Philbeck, 2008), increase the efficacy of therapeutic applications and increase transfer of training from VR to the real world (Minsky, 1980; Rose et al., 2005). Therefore, this finding is encouraging for the development of virtual reality route learning tasks for brain injury rehabilitation.

7.4.3 Is there a difference between conditions or groups in performance on a virtual route learning task?

The present study demonstrated that people with TBI perform worse on virtual route recall when only distal landmarks are available, unlike neurologically intact participants who perform similarly in each condition. Participants with TBI also scored lower on the virtual route recall task than the comparison group in both landmark conditions. These results are largely similar to those found by Livingstone et al. (2007) in which there were significant differences between the two groups when using distal landmarks. This finding lends some support to the theory that damage to the hippocampal region after TBI may be associated with specific allocentric processing deficits, which may lead to the inability to use distal landmarks to learn or remember a cognitive map. This study therefore extends the findings of Skelton and colleagues (Goodrich-Hunsaker et al., 2010; Livingstone & Skelton, 2007; Skelton et al., 2000) to route learning, in addition to place learning.

For people with TBI, the differences observed between landmark conditions may result from the way in which landmarks are encoded. Route learning studies in neurologically intact individuals have found that landmarks at decision points are encoded differentially and preferentially to those at non-decision points (Janzen, 2006; Janzen & Weststeijn, 2007) and that egocentric encoding activates the striatum, particularly the caudate nucleus (Bohbot et al., 2004, Iaria et al., 2003; Nadel & Hardt, 2004), whilst allocentric processing activates the hippocampus

(Burgess et al., 2002; O'Keefe & Nadel, 1979). It has been hypothesized that the results demonstrate the involvement of the different brain regions in encoding and it has also been found that this effect during recognition is independent of conscious recollection of the landmarks (Wegman & Janzen, 2011). These studies so far have not been able to gain a comprehensive picture of how landmarks interact with decision points and have not all used fully interactive virtual environments (e.g. Wegman & Janzen, 2011 used video segments of routes). They have also not made a comparison between proximal and distal landmarks, which would make for interesting further study.

In contrast to Livingstone and Skelton (2007), the present study also found a difference between the two groups in the proximal landmark condition. The differences found in the present study are unlikely to be due to a lack of feeling of presence in the environment in the TBI group, as both groups demonstrated high scores on both of these measures. These differences between groups in the proximal condition may be related to the greater level of difficulty of the current task. The virtual MWM used by Livingstone & Skelton (2007) required participants to locate one hidden platform next to a distinctive proximal object. Thus, not only was their study related to place learning rather than route learning but there was only one distinctive landmark, compared to the 15 landmarks located at fifteen decision points in the current study.

The results from the comparison group here are consistent with the findings of Steck and Mallot (2000) in that route learning performance in neurologically intact individuals was similar across both conditions and participants were able to use both proximal and distal landmarks when required. However, it is important that these results are interpreted with caution, given the small sample size. The authors suggest that this result occurred in their study even though participants had previously shown a preference for one type of landmark and thus demonstrated that both types of landmarks were nevertheless stored in memory. These current results are however, different to those found by Ruddle et al. (2011) where neurologically intact participants made significantly fewer errors in their proximal condition. As discussed earlier in the chapter, this may reflect the methodological issues which have been addressed in the current study i.e. ensuring that the proximal landmark condition contained no distal landmarks and using a single journey rather than return journeys which require a shift to allocentric perspective.

7.4.4 Is there a difference between the conditions or groups on map drawing or landmark recall?

Participants were asked to draw a sketch map of the route after each landmark condition in order to explore whether these differences were related to a deficit in forming or remembering a cognitive map. They were also asked to recall as many landmarks as they could. Participants with TBI scored significantly and consistently lower than the comparison group on the number of correctly recalled turns drawn on the map and also on free recall of landmarks. There was a significant main effect of landmark recall, with worst performance in the distal condition. Again, it is important to consider these results with caution given the small sample size in the present study and particularly, the results in the map drawing task, which resulted in a non-parametric analyses that suggested that both groups performed worse in the distal condition on map drawing even though the median scores were the same. Furthermore, it was not possible to investigate the interaction effect for map drawing. Both groups also performed worse on landmark recall in the distal condition. However, unlike the VR route recall, people with TBI were not proportionally more disadvantaged in the distal condition compared to the proximal. Of further interest is the discrepancy between the number of landmarks recalled and the number of correct turns drawn on the maps. Both groups recalled approximately half as many correct map turns as they did landmarks in the proximal condition. Although this was less obvious in the distal condition (possibly due to floor effects), it might suggest that although participants could recall the landmarks, they were not always able to recall the directional information associated with them.

7.4.5 Research question: Is there a difference between conditions or groups in performance on self-reported navigational strategies on a virtual route learning task?

Significant differences between the proximal and distal landmark conditions emerged on four questions: Using landmarks in the distance; use of buildings and landmarks along the way; using a verbal description of the route; and the development of a cognitive map. The first two provide tentative confirmation that the landmark conditions achieved what was intended i.e. more use of landmarks in the distance in the distal condition and more use of landmarks along the way in the proximal condition. The fact that a verbal description was used less in the distal condition is also consistent with the suggestion that an egocentric strategy (potentially using proximal landmarks) lends itself more to learning a list of lefts and right turns whereas a distal strategy relies on a cognitive map.

Differences between the TBI and comparison participants emerged on three of the navigational strategy questions: Guessing; following one's instincts and the use of buildings and landmarks. Participants with TBI reported more guessing and use of instinct and less use of buildings and landmarks along the way than the comparison group. One might speculate that either people with TBI were genuinely forced to guess in the face of uncertainty or they experienced a lack of explicit awareness of the route (Brooks et al., 1999). This may be a direct result of the implicit nature of the route learning task itself. As discussed earlier in the chapter, the route learning task was designed to be errorless in the learning trials, as this type of learning has been used successfully in participants with a brain injury on visuo-spatial (Nissley & Schmitter-Edgecombe, 2002) and route learning tasks (Lloyd et al., 2009b). The participant in the study by Rose et al. (1998) was able to successfully learn routes but was not aware that she had learned them. This is further supported by the work of Hartley et al (2003) who suggest that route learning may be more of an automatic process facilitated by stimulus response associations.

In summary, participants with TBI performed better in the proximal condition and worse in the distal condition in all test circumstances (route recall, map drawing and landmark recall). This is further supported by their self-reported use of navigational strategies which tentatively suggested that, even when only distal landmarks were available, they may use them less than neurologically intact controls and they rarely tried to develop a cognitive map. However, this was not tested statistically. People with TBI also performed generally worse than controls on all aspects of the study suggesting that route performance is impaired overall after TBI. These findings are consistent with the notion that the hippocampus, an anatomical structure that is crucial for route learning, is vulnerable to damage after TBI (Atkins, 2011; Kotapka et al., 1992; Mañeru et al., 2005; Tate & Bigler, 2000; Tomaiuolo et al., 2004), whilst the caudate is less likely to be affected by the injury (Serra-Grabulosa., 2005; Wilde, Bigler, Hunter, Fearing, Scheibel et al., 2007) and this therefore results in route learning difficulties. Furthermore, an allocentric strategy that relies on the use of distal landmarks for creating a cognitive map is mediated by the hippocampus (O'Keefe & Burgess, 1996; O'Keefe & Nadel, 1979) and therefore results in a selective deficit for people with TBI when only distal landmarks are available.

7.4.6 Limitations

The results in the present study show differing levels of stability. Where the data fitted most of the criteria for parametric analysis to be used, the analysis was applied and where the data violated more than one tested assumption necessary for parametric analysis, non-parametric statistics were applied (Field, 2009, pp. 131-165). There are inherent problems for studies of this size. With less than forty participants the results will not be affected in the same way that data with higher numbers of participants can be, namely that the data can show up as normally distributed and reflecting the general population, when it is not (central limit theorem) (Field, 2009, p. 156). However, as Field (2009, p. 156) explains, in small samples of less than forty participants, normal distribution is hard to identify as the tests have lower statistical power. The application of parametric statistics to the data that are within the expected parameters means the results are relatively robust (Field, 2009, p. 155). The use of non-parametric statistics means the tests are likely to give slightly lower estimates than may be achieved if the data met the criteria to use parametric analysis. However, taking these limitations into account, the overall results indicate that the use of proximal landmarks for individuals who have experienced a traumatic brain injury, may be more effective than using distal landmarks on a route learning task. We would caution that more research in this area would be beneficial, but this study shows it would be valuable research which would benefit those who may have serious problems with wayfinding.

Without the benefit of neuroimaging techniques it is not possible to know exactly which anatomical areas were related to task performance or which brain areas were affected in individual participants, so caution should also be applied to this interpretation. Unfortunately, it was not possible to obtain scans from the day centres from which participants were recruited. As the participants in the current study were not matched to those in Livingstone and Skelton's (2007) experiment and the tasks requirements and virtual environments were not matched, it is important to note that a direct comparison cannot be made. This, therefore remains a limitation of the current study and an area for future study. It would also be interesting to use the VR environments during scanning with fMRI. Nevertheless, the finding that people with TBI were differentially affected in the distal condition appears to be consistent and robust within this study.

It is also important to consider the nature or recognition and recall in a route learning task, which was not fully explored in the current study. Landmark recall was chosen as a measure in the current study as participants were not required to recognise one landmark from a series of landmarks at each choice point, whereas they were required to recall directional information at each choice point (i.e. which turning to take). The current study was specifically designed to test the use of proximal or distal landmarks on a route learning task, whilst allowing participants to select their own navigational strategy. This resulted in the decision to place only one landmark at each decision point, so as not to force participants into using an allocentric strategy in the proximal condition (as discussed earlier in the Chapter). It is hoped that this has provided a framework with which to begin to explore how these findings can be applied to rehabilitation for those who have wayfinding impairments. However, real world wayfinding will inevitably contain more than one landmark. Therefore, an important area for future research would be to include a measure of landmark recognition, to ensure that individuals can recognise the landmarks they are using to navigate from a series of other landmarks. In future research, this could be achieved by adding recognition tests after the route learning tests (e.g. in the form of pictures of landmarks or scenes from the decision points). The current study used famous landmarks as part of a screening procedure. It may be important to look for alternative methods, using different classes of objects for those who do not have difficulties with landmark recognition but are not familiar with the landmarks in the test. A further limitation of the study is that participants, particularly those with TBI, had difficulty drawing a map of the route. It is not possible to know whether this was related to an impaired ability to create, store or retrieve an allocentric representation of the environment (as suggested by Livingstone & Skelton, 2007) or whether there were other aspects of the task that impacted upon this result. For example, confidence in drawing ability or not being familiar with this type of task. The inclusion of the grid was designed to eliminate individual differences in drawing ability which have been encountered in previous studies (Golledge, 1999; Murray & Spencer, 1979; Shah & Miyake, 2005). Participants were not given any training on map drawing prior to testing in the current study so as not to influence their naturally chosen strategy (i.e. allocentric or egocentric processing). However, given that TBI participants had such difficulty with this task, future studies should consider an element of training to familiarise participants with this task.

The presence and navigational strategy questionnaires were both self-report measures and their use by individuals with TBI have been called into question, particularly relating to levels of self-awareness (Toglia & Kirk, 2000) and this may mean some of these measures were not necessarily a true reflection of the strategies being used. An interesting area for future research may be to use eye tracking software to monitor viewing behaviour and explore which aspects of the environment were being attended to, if the technology was acceptable to participants. Eye tracking is now being successfully used in wayfinding studies with neurologically intact participants and results have shown that verbal reports of landmarks which are being attended to are associated with gaze behaviour (Spiers at al., 2008) and eye tracking has been used in studies exploring whether objects are considered navigationally relevant (Wegman et al., 2011).

A further potential limitation of the study is that it is not possible to know whether the results found in the current study relate specifically to landmarks or whether the same results could be applied to general objects. However, recent research suggests that people process objects differently and recall more objects in route learning tasks, when they are placed at decision points along a route and are considered navigationally relevant (Chan et al., 2012; Janzen & van Turennout, 2004; Jansen-Osmann & Fuchs, 2006; Wegman & Janzen, 2011). This would make an interesting area for future research and landmarks could be adapted to explore this idea further.

The virtual environment used in the current study was designed to represent a more ecologically valid, real world environment but it is important to consider how much this actually reflected a real world scenario. For example some neurons in the hippocampus may respond differently to head movements and the level of visual input in the real world, which cannot necessarily be achieved in the same way in VR (Shinder, & Taube, 2014). Also some important vestibular cues which influence the firing of hippocampal cells during spatial processing, may not be fully activated during stationary navigation (Aghajan, et al., 2014; Taube et al., 2013). The findings off Sorita et al (2012) also suggest that there may some aspects of the environment which are not fully captured during VR wayfinding, although this did not affect route learning performance in their study, which showed equivalence in the route learning task performance across the two conditions. However, as previously discussed, a number of studies have continued to demonstrate the equivalence of wayfinding behaviour in virtual and real environments, as well as the transfer of training from VR (see Chapter 4). As previously discussed, virtual reality environments offer great potential in the assessment and rehabilitation of wayfinding difficulties, particularly when there are accompanying mobility limitations or safety concerns. However, these potential differences between real and virtual worlds highlight the importance of further testing and the development of a standardised measure of wayfinding which can be used in clinical practice.

7.4.7 Recommendations and clinical implications

The VR environment was successful in highlighting the relative strengths and weaknesses of people with TBI in terms of landmark use on a route learning task. It would however, benefit from a larger normative reference group and further exploration of changes across the age span. It would also benefit from further research to explore whether the beneficial effects of route learning using proximal landmarks transferred to a real world route learning task. With this data in place, the VE could be implemented in to clinical practice, to provide clinicians with a tool to assess wayfinding impairments earlier in the rehabilitation process and make recommendations regarding the use of landmarks in rehabilitation of real world route learning difficulties, with a view to increasing independence and participation. Specifically this may include that therapists could use the two routes to test whether people are a) impaired on the route learning test when compared to the comparison group/normative data and b) relatively worse with a specific landmark type. This may allow therapists to consider whether to place greater emphasis on route learning/navigation well before discharge and also to help them consider what type of landmarks to use whilst practising navigation in real life.

Findings of this study would also suggest that consideration needs to be given to whether rehabilitation for wayfinding difficulties should focus on facilitating the relatively intact skill of using proximal landmarks or supplementing this with the use of distal landmarks and this is addressed in the next chapter. Meanwhile, the findings herein have moved the field somewhat closer to having a landmark-based framework (i.e. the distinction between proximal and distal landmarks), on which to base potential strategies.

CHAPTER 8

Does the facilitation of distal landmark identification improve route learning after a traumatic brain injury: Two case studies

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8.1 Introduction

This chapter describes two case studies in which participants with TBI who showed a deficit in learning routes in VR when only distal landmarks were available, were helped to select distal landmarks to supplement their natural approach to real world route learning. The aim was to explore whether the participants found this approach acceptable and whether there was anecdotal evidence to suggest that this new strategy might be helpful. It was hoped that recommendations could then be made for a feasibility study that would lead to a main study exploring whether supplementing participants' natural strategies with an additional distal landmark strategy would improve real world route learning in people with TBI.

Chapter 7 of this thesis describes a study in which it was found that people with TBI suffered a proportionally greater disadvantage learning a VR route using distal cues in comparison to proximal cues, when compared to a neurologically intact control group. Given that the most efficient wayfinders are people who are able to adapt their wayfinding approach to the environment by switching between proximal and distal cues as necessary (Kato & Takeuchi, 2003), it was decided to try to teach participants a strategy to help them compensate for the skill in which they showed a deficit. It was hoped that this might lead to a new rehabilitative approach to route learning for people with TBI using landmarks.

There are very few studies exploring strategies to improve route learning in people with TBI, therefore this chapter will begin with a narrative review of the literature exploring strategies to improve route learning and wayfinding after a brain injury. It will be evident that many of the current approaches consist of bespoke interventions for people with specific lesions. However, many of these approaches incorporate a landmark-based strategy, which was chosen for the current intervention. A discussion then ensues about why landmarks should be used to assist route learning and how best to utilise them during rehabilitation. Two case studies will then be described that explore whether participants are able to utilise a distal landmark strategy in addition to their natural approach to route learning and whether there is anecdotal evidence for improvement using the proposed new strategy. Finally, recommendations for the design of a feasibility trial will be made.

8.1.1 Literature search

A literature search was carried out in order to identify existing studies which explore the rehabilitation of wayfinding difficulties after a brain injury. This section will first describe the literature search strategy, before going on to present a narrative review of the current evidence base.

The following databases were searched using the date range of 1900 to 2009: CAB Abstracts, CINAHL, EMBASE, MEDLINE, PubMed and PsycINFO. The search period was set but the earliest study found was from 1944. The search terms are provided in Table 8.1 and boolean search terms were used where appropriate (e.g. brain AND injury). Published, peer reviewed studies relating to brain injury were included if they contained at least one term in two of the three categories listed in the table below. Abstracts were reviewed to eliminate articles based on the following exclusion criteria: participants who were under the age of eighteen, participants who did not have a brain injury, animal studies, unpublished papers or those which were not written in English language. In addition, the reference lists of the selected articles were searched by hand to capture any further relevant papers. The literature review included papers up to 2014. This resulted in only 16 studies which are described below. This highlights that despite the prevalence of wayfinding difficulties after ABI, there is still limited research to inform rehabilitation.

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Table 8.1: *Literature review search terms and papers reviewed*

Category	*Search term*	*Total results*	*Limit to 1 & 2*	*Limit to 1 & 3*	*Papers removed*	*Abstract read*	*Papers from manual search*	*Papers included which met the inclusion criteria*
1. Brain injury	Stroke, brain injur*, head injur*, TBI, ABI, head trauma, stroke	461,448						
2. Wayfinding	Wayfind*, navigat*, spatial memory, route learn*, topographical disorientation	1,508	493		454	49	12	14
3. Rehabilitation	Rehab*, training, retraining	9,489		49	48	1	2	2

8.1.2 Approaches to rehabilitation

One of the key issues in neuropsychological rehabilitation is whether to focus on the restoration of a lost function or to concentrate on providing individuals with a strategy to compensate for this loss (Wilson, 2008). This question was first posed by Zangwill in 1947, who discussed the application of restitution and compensation in brain injury rehabilitation. ‘Restitution’ involves the restoration of an impaired function through direct training, so that pre-injury functioning is restored (Ponsford et al., 2012). In contrast, ‘compensation’ was described by Zangwill (1947) as “reorganisation of psychological function in order to minimize or circumvent a particular disability” (p. 63) and involves using an intact skill/strategy to compensate for the loss of function to achieve a goal in an alternative way. An example of a compensatory strategy for people with wayfinding impairments might be to use an external aid to reach a destination (e.g. to follow a list of directions), if these skills were still intact.

These two approaches are also reflected in the International Classification of Functioning (ICF) (WHO, 2002) framework which describes rehabilitation strategies which aim to reduce activity limitation/participation restrictions or alternatively, to restore impaired mental function. The 16 studies that were found were therefore classified according to the approach adopted and are described below (see Appendix K for summaries).

8.1.3 Compensatory strategies

Compensatory strategies tend to focus on improvements on tasks which can increase participation and functional outcome, rather than the restoration of a lost function. They can take a number of forms and Wilson, Gracey, Malley, Bateman and Evans (2009) suggested four broad categories. ‘External aids’, such as a diary or a checklist, can be used to compensate for memory difficulties. ‘Cognitive compensation’ involves using a cognitive strategy, such as counting to ten, to manage anger. ‘Environmental adaption’ involves changing the surroundings, such as completing a task in a quiet room to compensate for attentional difficulties and finally, ‘enhanced learning’ approaches use methods such as errorless learning to increase uptake of skills. The majority of studies included in this review use at least one of the four compensatory approaches but it should be noted that a combination of strategies is often used. This narrative review is designed to provide an overview of the studies found in the literature search and further details of the studies can also be found in Appendix K.

8.1.3.1 External aids: using technology

Two studies have explored issues surrounding the provision of on-line directional guidance for people with ABI using hand-held personal digital assistants (PDA) as external compensatory aids. These can be any kind of hand-held, mobile device which can provide computing information (Fickas, Hung and Fortier (2007). In the first study, Sohlberg et al. (2007) investigated the use of four prompt modes on a real world route following task, using a within-subjects design. Participants were recruited from a local supported living facility (*N* = 20) and asked to follow a route using directional prompts given to them directly them on the screen of the PDA. All participants tested all four prompt modes separately. Directional instructions were indicated by overlaying arrows on an aerial map image (bird's eye view), a map image from the first person viewpoint (worm's eye view), written text (no arrows or image) and via audio directions. Participants were required to walk around a real world route and they received directional instructions on a PDA. Participants were accompanied by two researchers, who used their own PDA's to deliver the route instructions (e.g. turn left when you get to the intersection) at the same place on each route for each participant. The researchers recorded route following scores and at the end of all four prompt mode trials, participants were asked to rank the prompt modes in order of most to least helpful. The results indicated that participants performed best on the route following task when receiving the audio instructions and this was also the method preferred by most participants. The authors suggested that this may have been because the visual demands of the picture/map-based prompts competed with the visual demands of the route following task, whereas the audio prompts did not. However, as participants were asked to rate the prompt modes at the end of the study, rather than after using each prompt mode, it is difficult to know whether these results were confounded by potential memory difficulties.

A study by Liu, Hile, Kautz, Borriello, Brown, et al. (2008) describes a different preference for the presentation of directional information. In this study, seven participants with cognitive impairments (2 with a TBI) completed a similar route following task in an indoor environment and tested three different prompt modes on a PDA. The first used a photograph, audio instructions and text. The second used text and audio instructions and the final mode used a photograph and text-based instructions. Participants responses varied greatly but most found auditory commands too fleeting, preferring text and/or images which were displayed continuously and could be referred to at any time. However, the authors suggest that the timing of when directions were given may have influenced the results and those given too early (well before the turning) may place more demands on working memory than those given just before the turning (Meilinger et al., 2014).

There are numerous methodological differences between these studies e.g. indoor versus outdoor environments, whether or not an aerial/cognitive map condition was used, differing timing or prompts and whether prompts were re-delivered, making it very difficult to make direct comparisons. Nevertheless, several important suggestions arise from these studies; such as the need to time prompts appropriately, have the facility to replay prompts in order to allow for working memory problems and the need for the participant to be able to perform reliable right/left recognition if auditory or text-based prompts are used. It is also necessary to consider the cognitive demands of the strategy alongside the cognitive demands of the wayfinding task. For people who have limited cognitive resources, the visuo-motor demands of wayfinding may compete with the cognitive demands of map reading, which was the mode of prompting least preferred by Sohlberg et al's (2007) participants.

Although there are no existing studies in this area, another technological solution to assist navigation is the use of global positioning systems (GPS) which can also be incorporated into mobile phone software (Brown, McHugh, Standen, Evett, Shopland et al., 2010). However, the passive nature of GPS guidance, which also tends to be route-based, facilitates navigation, rather than route learning per se and may even hamper the incidental learning of survey information (i.e. all allocentric representation of the environment or cognitive map), even in people without cognitive problems (Münzer, Zimmer, Schwalm, Baus & Aslan. 2006). This may suppress the development of cognitive or mental maps (Oliver & Burnett, 2008), which can provide a more comprehensive representation of the environment and have been linked to improved route finding abilities, partly because when a familiar route is blocked or unavailable a mental map allows one to consider an alternative direction of travel or take a shortcut (Hartley et al., 2003).

Thus, technological solutions can be helpful if they can be individualised to meet the needs of the person and their environment. However, the use of such systems requires training, which in itself may be a challenge for people with brain injury (Evans et al., 2003). Furthermore, studies report that participants worry about the stigma of carrying around a compensatory device (Sohlberg et al, 2007) and it is particularly important for them to have contact with another person if they get lost, experience high levels of anxiety or the technology itself fails (Lemoncello et al, 2010a). Such caveats imply that an electronic aid may not always be the best solution, whereas a written aid or an internal strategy such as the landmark strategy proposed in the present study, might be a more suitable solution.

8.1.3.2 External aids: written aids

Surprisingly, only two studies to date, report the use of an external written or visual compensatory aid for wayfinding rehabilitation (Newbigging & Laskey, 1996 and Lemoncello et al, 2010a). In a study by Newbigging and Laskey (1996), a 28 year old man who experienced memory difficulties after a TBI learned to travel to his vocational placement by bus. Prior to travelling, the chosen routes were traced on a map. During travel, a checklist of prompts consisting of landmarks or street names was provided and each step was ticked off along the route. At the end of the training period the participant had learned three bus routes and a further four routes had been added and remembered at a 12 year follow up. The authors report that these new routes were learned using the methods they described but is not clear how much support was given during this time. As well as being an uncontrolled study, no rationale is given for this choice of strategy and it has multiple components and therefore, it is not possible to attribute effects. However, it provides anecdotal evidence that the approach was successful and the authors reported that the participant was able to reorient himself if he became lost, potentially because tracing the map had allowed him to develop some survey knowledge. It is also possible that the use of a checklist minimised errors and resulted in more effective learning (Clare & Jones, 2008). Overall, it supports the use of practical in-vivo training, which was supplemented by planning sessions. The downside of this approach is that it would be very time intensive for the therapist and it is unclear whether it would be possible to generalise the approach to other situations in the absence of a therapist.

In a second study exploring the use of written aids, Lemoncello et al (2010a) asked participants with ABI (n = 18) and a matched comparison group (n = 18) to orientate themselves on a wayfinding task, using one of three written directional prompts. They compared the use of different types of cues that contained landmarks, cardinal (compass points) or left/right directions. Participants were given the cues on cards and taken to a street intersection. They had to use the cues to orientate themselves, rather than starting facing the correction. The researchers found fewest errors were made in the landmark cue condition and this method was preferred by participants with ABI and matched controls. However, it is not possible to isolate the comparative differences amongst the different prompt modes as all the conditions included some left/right directions e.g. in the cardinal condition, which should only have included compass-based directions, participants were asked to "face south...and turn *right* onto a street" (p. 545). This cue contained both cardinal and left/right directions. It is also not clear whether the landmark cues were proximal or distal. It is, however, notable that participants found the landmark-based approach both preferable from their own ratings and most effective on orientation scores and a landmark-based approach is therefore, adopted in the present study.

In summary, although there is a very small amount of anecdotal evidence that written aids alone may be helpful for some people with ABI, they may not be suitable for everyone. For example, people with acquired dyslexia would not be able to use them. The approach may also be very time intensive for the therapist and there is no clear evidence of generalisability as yet. A cognitive approach such as that used in the present study may, therefore, be more helpful. Other cognitive approaches that have been used to date, are discussed below.

8.1.3.3 Cognitive compensatory strategies

Six descriptive accounts provide insight into the cognitive compensatory strategies that are either naturally developed by people with wayfinding problems or developed with a therapist (Bouwmeester et al., 2014; Ciaramelli, 2008; Davis & Coltheart, 1999; Incoccia, Magnotti, Iaria, Piccardi and Guariglia, 2009; Paterson &

Zangwill, 1945 Rainville et al., 2005). Two of these case descriptions give an account of individuals' use of smaller features in the environment such as street/building names and colours/shapes within landmarks in order to compensate for difficulty creating a complete percept of a landmark i.e. due to landmark agnosia (Paterson & Zangwill, 1945; Rainville et al., 2005).

Rainville at al. (2005) explored the ability of a 71 year old man with prosopagnosia and topographical agnosia to orient himself in familiar and new environments using street names, as he had demonstrated particular difficulties recognising both famous and familiar landmarks to the authors. The participant completed a series of tasks designed by the researchers to explore the extent of his difficulties. In two outdoor tasks he was required to find his way to a location in a familiar town via an unfamiliar route. He was driven from a starting to location to a goal destination via a non-direct route (i.e. a route that he would not usually take). He was then asked to return to the starting point using the same route he had just seen. He was asked to express verbally what he was looking for during the task (e.g. landmarks, street signs) and if he was not able to verbalise his strategy, he was simply asked to state what he was doing and why he was doing it, to identify when and where he was making decisions. He also completed a pointing task on both routes, where he was asked to point to four locations which were not visible from his current position and estimate the distance between four sets of locations during the route. This task was designed to test his cognitive map of the environment. His performance on these tasks was compared to the performance of a small, age matched control group of five participants. He was also asked to learn a new route in an unfamiliar town, using the same procedures.

The researchers report that in the familiar town his performance was comparable with controls on the route learning task and the pointing task. During the task in the familiar location, he was unable to recognise landmarks that had always been present in the town but he was able to plan how he was going to learn the route. His own strategy was to analyse components of the route and plan to remember names of landmarks (e,g, street names and restaurants). In the unfamiliar town, he completed the same task but was only able to complete 10 out of the 21 decision points correctly, which was significantly worse than controls. Interestingly, despite his difficulties recognising landmarks, he did acquire some spatial information of the unfamiliar route. The results of the pointing task showed there was no significant difference between his performance and the control group when estimating distances. Many of the landmarks in the pointing task were distal and the authors suggest that this demonstrates some ability to use landmarks to form a cognitive map of environment. Thus, the participant's ability to plan his strategy and use written components of the environment were helpful in helping him navigate a familiar environment. The challenges faced by this individual highlight the importance of landmarks for day-to-day navigation and route learning. Although the focus of the present study is on people with TBI rather than people with specific lesions, they will be assessed for landmark agnosia prior to taking part. This study also suggests that that distal landmarks may be beneficial during route learning to help build a cognitive map of the environment but it also highlights the importance of allowing the participant to select landmarks which are relevant to them during route learning.

A recent and similar case study describes the wayfinding difficulties of RB, an individual who is described as having TD as a result of a stroke (Bouwmeester et al., 2014). RB suffered damage to the right occipito-temporal region, which affected his ability to differentiate objects within categories (e.g. he could not differentiate between a soup bowl and a coffee cup), to identify relevant landmarks or obtain any directional information from them (e.g. turn right at the church). Numerous unsuccessful attempts at employing strategies were made by his family and the researchers, until specific strategies were discovered. These focused on completing tasks which were personally meaningful to him (walking a route to his library where he liked to read books) and also included very specific details of the environment. Strategies included developing sets of directions, which contained smaller details of his chosen landmarks (without background or environmental information) and all with concise, written directions and some additional pictures of the features he was using. The researchers report that these were successful after many years of training and RB was also able to learn a set of new routes. After following RB for 12 years and assisting with his training, he was eventually able to walk the trained routes without the cues. He was also able to identify new landmarks to use in the learning of new routes but relied on others to help him develop the written instructions and materials for them. The lack of a cognitive model or framework on the part of the therapists resulted in numerous attempts to develop a set of procedure to help RB. This was a particularly time consuming process, which would not be practical in a rehabilitation setting. However, it again highlights the importance of utilising features in the environment which are personally meaningful to the individual, if they are to be used for route learning rehabilitation.

In one other case study of topographical agnosia, Paterson & Zangwill, (1944) describe the case of a 34 year old man who had suffered a penetrating head injury in the right parietal region. He suffered from visuo-spatial neglect, landmark agnosia and apraxia. This was an assessment and observational study rather than an intervention, whereby the authors observed the client in the hospital and navigating around his local home environment. Similar to the strategies taught by Rainville et al. (2005) and Bouwmeester et al. (20014), the participant had naturally developed his own compensatory strategy for wayfinding which was to focus on smaller environmental cues such as signs on buildings, colours and other very small features in the environment that mitigated the need for the creation of a complete percept of a landmark. These three case studies of people with landmark agnosia thus illustrate the importance of landmarks and environmental cues for navigation. The earliest case by Peterson and Zangwill (1944) further illustrates how one participant had naturally developed a compensatory strategy to help him navigate and this still focussed on features in the environment rather than, for example, attempting to recall right and left turns or using a checklist.

A descriptive account of an internal strategy to compensate for wayfinding problems that was very different to those described above, is given by Ciaramelli (2008). The 56 year old man had suffered a subarachnoid haemorrhage and the basis of his problem seemed to be an executive deficit causing him to go off track during wayfinding. He was able to recognise landmarks and was able to walk familiar routes in his town but during observation session with the researcher, would regularly become distracted and head to different locations during route navigation. However, when he was asked, he was able to recall his goal location. The researchers report that in order to compensate for this, he was encouraged to rehearse his goal during travel. This worked well in this case and generalised to other areas of his life, such as grocery shopping. It is not possible to know whether this was a direct result of the training or whether spontaneous recovery occurred but this study does indicate the importance of strategies which can be used to reduce distractions during active navigation and those which encourage individuals to keep their goals in mind during the task (Burgess, 1996; Badre & Wagner, 2007).

Another type of internal strategy is described in a case study by Davis and Coltheart (1999). In this instance, the intervention involved the development of mnemonics which aided verbal route memory for a woman who experienced the sudden onset of route learning difficulties, after a severe migraine. A mnemonic was developed for street names along a route, which was then incorporated into a series of sentences that were used as she walked the route. This approach was successful but it is notable that she had only mild memory problems. As noted by Richardson (1995), the benefits of mnemonics tend to be inversely related to the degree of memory deficit. Furthermore, after several years it was clear that in this instance it was not long lasting as she had abandoned this strategy and reverted to a preferred strategy involving describing the route verbally to herself using landmark features in the environment e.g. “go over the bridge, …turn left at the lights”. This illustrates that like written prompts and checklists, such a strategy is time intensive and may not generalise. It also again illustrates how the participant showed a natural inclination to incorporate landmarks in the environment into her own strategy.

A further study by Incoccia et al (2009) which uses both cognitive and written strategies, describes a participant who had never learned to navigate due to a cerebral malformation involving the retrorolandic regions. The authors report that she had never developed wayfinding skills and demonstrated difficulties orientating herself in the environment. She did not go out unaccompanied for fear of getting lost and reported regularly getting lost if she lost sight of her mother in the grocery store. The aim of the study was to attempt to familiarise the participant with alternative compensatory strategies, which also included an element of written and language-based strategies. During the study the participant first learned to explore the environment around her. She was then given training to orient herself and process environmental cues. This involved learning to search the environment for landmarks and recognising differences in pairs of photographs of similar scenes. She was also trained to mentally rotate objects and draw maps of external environments to encourage the allocentric processing. During the second stage, she was trained to use written and language-based strategies to navigate in real environments (e.g. to walk short distances) and to write down route descriptions and directional information. These included a verbal description of the route, which she could follow. She required help with this stage but by the end of the training, the participant showed improvements in her navigational abilities and importantly for her and her family, was much more confident in her navigational skills. At a one year follow up, she had learned to navigate to several new locations and the researchers suggest that although her specific visuo-spatial skills had not improved on neuropsychological tests, the training had allowed her to become aware of her difficulties and learn how to compensate for them.

In summary, these six uncontrolled cases illustrate that aside from mnemonics, there is anecdotal evidence that internal strategies tend to be acceptable to participants, may be less time intensive to learn and may generalise. Furthermore, participants seem to naturally revert to a strategy that involves environmental cues including landmarks when possible. It is clear that many of these studies involve an element of other types of aids, such as written or verbal elements. However, in the study by Incoccia et al (2009) the compensatory strategy provided an opportunity to increase the participant's awareness of their difficulties and allowed them to develop strategies to cope with this, with support from a therapist. Cognitive compensatory strategies therefore, offer great potential to reduce activity limitation and increase participation after a brain injury and the current study will therefore, include an internal strategy.

8.1.3.4 Environmental Adaption

There are no single interventions described in the literature that involve manipulating the environment in order to improve route learning. However, Antonakos (2004) describes how three participants naturally altered their own environment in order to cope with TD. The author explored compensatory wayfinding behaviours in three individuals with ABI through interviews and all three participants had marked difficulty in developing or using spatial information, such that they did not have access to spatial knowledge of their environment and relied on systematic scanning to find relevant cues to prompt the direction of travel. Their home environments were as open and orderly as possible to allow these cues to be easily spotted (e.g. doors were always left open so that they could find the bathroom). One participant reported difficulty locating objects in the home but used prompted visual search strategies (e.g. reminded herself to ‘‘look to the left’’) which she also applied to real world navigation. Careful planning was reported in order to carry out tasks which were difficult and this was also applied to real world navigation (e.g. planning a trip using detailed written directions).

In sum, there are no environmental adaption intervention studies described in the literature for outdoor wayfinding tasks but the case studies described by Antonakos (2004) suggest that the environmental adaptions made by individuals in their own homes (e.g. leaving doors open) and the strategies they used (visual scanning, careful planning) may be a reflection of how they naturally adapt their environment and, subsequently provide an indication of the strategies which may be useful to help therapists improve related wayfinding impairments. However, with the limited literature base at present, environmental adaption was not considered for the current study.

8.1.3.5 Enhanced learning strategies

The main focus of study in this area has been on errorless learning which would be expected to facilitate route learning, as it has been shown to facilitate the learning of procedural skills (Maxwell, Masters, Kerr & Weedon, 2001) and route learning is mainly a procedural task (Garden, Cornoldi & Logie, 2002). These studies vary in the nature of the tasks employed to train and test the relative merit of errorless versus trial and error approaches. For example, Evans, Wilson, Schuri, Andrade, Baddeley et al. (2000) used two dimensional paper and pencil drawings in their training phase to learn a route, whereas Lloyd et al. (2009b) and Brookes et al. (1999) used virtual environments for route learning (further details of VR studies involving wayfinding have been discussed in Chapters 5 and 6 and see Appendix K for further details of these studies). Paper and pencil tests are clearly not analogous to real world route learning, whereas VR training and recall at least involve movement through three dimensional space and there is evidence these skills transfer to the real world (Darken & Banker, 1998; Farrell et al., 2003). The only study that has used a real outdoor environment on an errorless route learning task is Kessels, van Loon and Wester (2007). Ten participants with Korsakoff amnesia learned a route in the grounds of a hospital. In the errorless condition, all participants were shown a photograph of the correct route choice at each decision point and told which way to go. In the errorful condition participants learned a different route and were shown a photograph at each decision point but instead, were asked to choose which direction to take. The authors reported no difference in the route learning scores.

Overall, findings with regard to the benefit of errorless learning over trial and error learning for the acquisition of routes have been mixed. Two studies showed no benefit (Evans et al., 2000; Kessels et al., 2007), one study showed an advantage (Lloyd et al., 2009b) and one study showed that it was helpful, albeit without reference to a trial and error comparison condition (Brooks & McNeil, 1999). Negative findings may in part be due to methodological problems given that the environment used by Evans et al. (2002) was not analogous to real life and in the study by Kessels et al. (2007) it is questionable whether errors were encoded in their errorful condition as participants do not appear to have been allowed to actually embark on an incorrect course. Thus, in the present study the route learning trials will involve following the researcher so that errors are minimised during learning.

8.1.4 Restitution strategies

Restitution or direct retraining approaches usually involve using neuropsychological assessments to isolate a specific impairment and then repeated training exercises are used to target the impairment (Ponsford & Sloan, 2012). The goal of this type of approach is to improve performance on a specific task and this is attempted through repeated, targeted practice which may, over time, bring about changes to the brain (Kleim & Jones, 2008).

Strategies for wayfinding impairments that are purely restitutional do not feature in the literature. One reason for this may be that restitution interventions tend to focus on one specific deficit that is required for a task but in order to navigate a route successfully, a number of skills and brain regions are involved and therefore, this type of approach may not be entirely suitable. Participation in training on specific tasks which addresses each skill in turn would be time consuming for the therapist and potentially overwhelming for the patient.

Well-controlled studies of restitutional approaches have mainly entailed remediating attentional problems (e.g. Sohlberg, McLaughlin, Pavese, Heidrich & Posneet, 2000) and have shown limited generalisation to everyday activities. As argued by Ponsford & Sloan (2012) and echoed in the ICF framework, skills acquired in therapy should ultimately be applied to real world activities if they are to reduce activity limitations and increase participation. Thus in the present study, whilst the focus is on a skill that appears to be impaired (the ability to use distal landmarks for navigation), the aim is to give participants a strategy to draw their attention to this deficit in the real world and hence to encourage the use of these landmarks, rather than any claim being made for restoring a lost function.

Some authors have adopted a similar approach in tasks which hold a visual component, such as visual scanning of the environment in people with neglect (Katz, Ring, Naveh, Kizony, Feintuch et al., 2005; Van Kessel, Geurts, Brouwer & Fasotti, 2013). Thus, it could be argued that the increased performance on visual scanning or attentional tasks may be the result of behavioural compensation (i.e. implementing a chosen strategy), rather than an improvement in the impairment itself, similarly to the case study described by Incoccia (2009). The concept that a compensatory strategy may also increase awareness of deficits and improve rehabilitation outcomes has also been suggested with reference to general compensatory training after a brain injury (Ponsford et al., 2012). However, the visual nature of a route learning task where the environment is scanned for relevant landmarks, may lend itself to this type of approach and the current study will seek encourage participants to scan the environment for landmarks during the training condition.

8.1.5 How and why should landmarks be used during rehabilitation of wayfinding and route learning?

As discussed above, participants naturally adopt an approach during wayfinding or route learning that involves looking for cues in the environment such as landmarks (Ciaramelli, 2008). Landmarks that are proximal to the individual are important when using an egocentric approach, whereas distal landmarks may facilitate the acquisition of survey knowledge for an allocentric approach (Livingstone & Skelton, 2007). Effective wayfinders have been shown to switch from an allocentric to an egocentric strategy when distal landmarks are removed (Bohbot et al., 2004; Kato & Takeuchi, 2003). Thus, overall, the most efficient wayfinders may be those who are more flexible in their use of strategies, being able to switch as the environment changes (Kato & Takeuchi, 2003). Therefore, given the participants in the previous study have shown a deficit in using distal landmarks rather than proximal, they will be trained to use distal landmarks in order to supplement their natural wayfinding approach.

However, it is also important to consider the features of the landmark that will help to optimise performance. Chan et al., suggests that a good landmark for navigation will be dependent on the relevance to the individual. However, such choices/preferences may be counter-intuitive to other important properties e.g. landmarks that are not stable, such as parked cars, should be avoided (Burnett, 2000). Where possible, landmarks should be visually prominent, standing out somewhat from their environment (Sorrows & Hirtle, 1999); based at decision points along the route (Janzen & Weststeijn, 2007; Wegman, Tyborowska, & Janzen, 2014) and in the direction of heading (Janzen, 2006). Antonakos (2004) suggests that observation of the way in which patients navigate space, or asking them to verbalise their strategies, may give the therapist particular clues about difficulties and preferences with regard to landmarks. In preparation for a feasibility study, in the present case studies, participants will be asked to choose their own landmarks in order to establish whether such free choice reflects an underlying deficit and also whether it is likely to result in the selection of landmarks that are unlikely to be helpful, such as those described above.

In summary, the studies described above, many of them longitudinal case studies, suggest that route learning deficits may be amenable to compensatory strategies but approaches vary greatly. Landmark-based strategies are frequently reported and used successfully but there is no clear framework for building this into rehabilitation practices. In order to improve rehabilitation outcomes and increase participation, it is important to explore a way in which these landmarks strategies can be applied on a wider scale. Therefore, the strategy chosen for the present study will be landmark-based, with a focus on raising awareness and training in the use of distal landmarks (given that participants appear to be able to utilise proximal landmarks already during VR). It is hoped that the visual nature of the task (looking for and selecting landmarks in the environment) may facilitate an approach that seeks to derive the benefit from a compensatory approach (i.e. teaching a strategy to compensate for potential difficulties using landmarks) and also one with the potential to increase awareness of deficits and ultimately, after further testing in the form of a feasibility study, improve rehabilitation outcomes.

8.1.6 Research Questions

Given that the proposed strategy has not been applied before, the present study will consider:

- Is the proposed strategy feasible i.e. are the two participants able to select distal landmarks in the environment and if so can they use them?

- Is there any anecdotal evidence that this approach might benefit people with TBI?

- What can be learned from the two case studies that could inform a feasibility trial?

Given that a feasibility does not test outcomes, the main study, which we hope would follow the feasibility study, would then seek to explore the following research question:

- Does teaching participants an additional distal-based landmark strategy to supplement their naturally chosen strategy result in better route learning?

8.2 Real world routes

A within-participants design exploring the benefit of adding a distal landmark strategy to the participant's naturally chosen route learning strategy, requires two equivalent real world routes, which can be counterbalanced. Therefore, the method section first provides details about how the real world routes were selected and tested, before moving on to describe the two case studies in turn.

8.2.1 Real world route selection

The researcher selected the routes by first performing a visual scan of the local area using Google Maps© (2012). Ethical review of the study had stipulated that participants would be transported to the real world test locations via taxi for insurance and safety purposes. It was decided that the travelling time to each location would be limited to a maximum of 15 minutes by taxi from the planned Headway recruitment centre as this would minimise fatigue for the participants and work within time and budgetary constraints. In addition, the two routes would need a similar housing style/period, flat terrain, safe road crossings such as pedestrian crossings, contain up to fifteen turnings, allowed for a circular route to be walked and a similar number of left, right and straight on choice points. The decision to include 15 turnings was based on previous research on route learning after brain injury, which used between 12-15 turnings (Lloyd et al., 2009b; Sorita, et al., 2012) and should provide a balance between difficulty and fatigue effects. Other features of the routes would have to be excluded on the basis of both safety and methodological grounds. These are sloping streets or hills, uneven surfaces/badly paved areas, high pavements, very busy/main roads without safe crossings, any highly distinctive landmarks which were atypical of an urban environment, a route where turnings overlap (e.g. where the same turning had to be used more than once) or one that was not a circular route (i.e. which meant that the participant was required to walk a greater distance to return to the start point).

Thus, areas that were up to 15 minutes away by car (approximately 5.5 miles) were highlighted on a local map and these were explored further using Google Streetview© software (2012). Surprisingly few potential routes matched these criteria and only three routes were selected. These were visited by the researcher to assess suitability. One route was deemed unsuitable due to a lack of safe road crossings but two routes met all criteria. Both Route A and Route B were based in a Birmingham suburb and were 14 minutes by car from the recruitment centre (travel time estimated by Google Maps©).

Figure 8.1: *Real world route learning map for Route A*

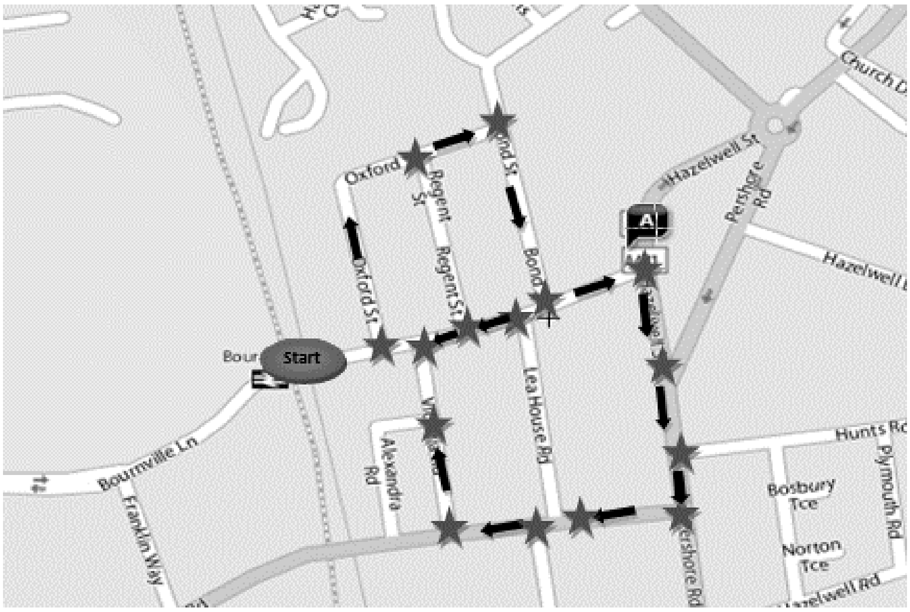

Figure 8.2: *Real world route learning map for Route B*

8.2.2 Route equivalence

The recruitment procedure and inclusion/exclusion criteria were the same as the case studies described below. A sample of three men and three women took part in the study, aged between and (*M* = 45.5 years, *SD* = 11.34*).* All participants had suffered a TBI and the mean time since injury was 9 years. Participants completed a route learning test on Route A in one session and Route B in the other session. The sessions were two weeks apart and the order of the routes was counterbalanced. For each route learning test, participants were positioned at the start point and instructed to try to remember the route as they walked around it with the researcher. After the participants had walked around the route once with the researcher, they returned to the start point and were asked to lead the researcher round the route they had just travelled. The researcher noted down the number of correct turns and the time it took to walk the route. There was no missing data, as the tests had been conducted by the researcher. Further investigation using the 'Explore' options is SPSS in accordance with Field (2007) revealed that there were no outliers. The data met the criteria for a parametric repeated measures *t*-test as for each test the data were normally distributed, there was a categorical variable (route) and a continuous variable (number of correct turnings and time taken to complete the route) and participants took part in both conditions (Field, 2009; Pallant, 2007).

The first *t*-test showed that there was no significant difference between Route A (*M* = 11.68, *SD* = 3.27) and Route B (*M* = 11.17, *SD* = 3.72) on the number of correct turnings made $t(4) = .19$, $p = .850$). The second *t*-test showed that there was no difference between Route A (*M* = 21.33, *SD* = 2.14) and Route B (*M* = 19.61, *SD* = 2.73) on the time taken to walk the routes $t(5) = .69$, $p = .521$). Therefore, the routes were deemed acceptable to use for the two case studies.

8.3 Case Study 1

RD was 38 years old, he had sustained a TBI 17 years prior to the study, as a pedestrian hit by a motorcycle. RD was recruited from the local Headway service which he was attending three times per week. Both RD's self-reporting and limited available past medical history from the rehabilitation centre suggested a severe TBI with a period of coma including the need for a tracheotomy and a prolonged period of rehabilitation that included a stay in a local acute hospital, a post-acute rehabilitation in-patient unit and a neurobehavioural unit for over a year. RD left school at 16 without qualifications and had worked as a steel cutter and in a games arcade. At the time of testing he was attending a local Headway day centre three days each week. Although he had learned to travel by bus to Headway, RD reported that any other journeys that he made alone involved the same bus routes e.g. routine trips to the shops. Both RD and staff at the centre reported that he had difficulty learning new routes. RD had taken part in the study described in Chapter 7. He had therefore, undergone a series of demographic and screening tests as part of this study as described below.

8.3.1 Neuropsychological assessment

A previous study suggested that the spatial addition and symbol span sub-tests of the WMS-IV; Wechsler, 2009) and the AMIPB list learning task (Coughlan &

Hollows, 1985) were correlated with recall scores on a VR route learning task (Lloyd 2007). These had been administered to RD as part of the previous study described in Chapter 7, in order to describe the nature of any pertinent cognitive deficits. RD scored below the first percentile (impaired range) on both the learning component of the AMIPB list learning test and the delayed recall of the list. He scored in the 'below average' range on the WMS-IV spatial addition test (16th percentile) and in the 'well below average' range (9th percentile) on symbol span.

8.3.2 Landmark recognition

The landmark recognition test was used as a screen for landmark agnosia (see Chapter 7) to ensure that this did not account for any difficulties that RD might experience learning the route. Participants were required to identify pictures of five famous landmarks. RD obtained a maximum score of five out of five on the landmark recognition task. This shows that he did not suffer from landmark agnosia, was able to create whole percept of each landmark and could name them.

8.3.3 VR route learning test

The VR study described in Chapter 7 showed that people with TBI were relatively disadvantaged when only distal landmarks were available for route learning compared to when only proximal landmarks were available, unlike a neurologically intact control group who showed a similar performance in each condition. In the proximal landmark condition RD had scored 11 out of 15 for VR route recall and in the distal landmark condition he scored only four out of 15. After each route recall test in VR, participants were asked to recall as many landmarks as they could, in the proximal condition RD recalled 6 out of 15 landmarks and in the distal condition he only recalled one landmark. Thus, his results demonstrated a relative deficit in the distal condition for both route recall and landmark recall.

8.3.4 Method

8.3.4.1 Design

The study was a within participants design with a baseline condition consisting of two learning trials and two test trials (the second being used to control for practice effects). This was followed by an intervention condition consisting of one learning and test trial without the intervention strategy, and one learning and test trial with the intervention strategy (see Table 8.2).

8.3.4.2 Materials

8.3.4.2.1 Real world route learning

Two equivalent real world routes in a Birmingham suburb were chosen for use in this study and these are described in detail above.

8.3.4.3 Procedure

Ethical approval for the study was granted by the NHS Birmingham Research Ethics Committee (see Appendix A).

Key workers at two local Headway centres and one local rehabilitation service distributed leaflets to those who met the inclusion criteria. These were a TBI, at least 6 months post-injury, older than 18 years at the time of injury and difficulties with everyday navigation as reported by the client themselves and their key workers. Exclusion criteria were marked comprehension or physical difficulties that would make it difficult to walk the route and familiarity with the real world test routes, which was asked by the researcher and by the keyworkers. This resulted in approximately 40 information leaflets being distributed over a period of two months. However, only 15 participants expressed an interest in taking part and of those, only 5 participants were able to meet the physical demands of the task (i.e. were able to walk for the required length of time). After discussion with each, it transpired that one suffered from motion sickness so would not be able to do the VR route, one was involved in a legal case and was advised not to take part for legal reasons and one had a severe mental health condition and would find it difficult to focus on the task.

As noted above, RD was recruited from one of the local Headway services and he had taken part in the study described in Chapter 7. After reading the information leaflet for the present study, he approached the researcher who was often on site at Headway, and volunteered to take part. After giving informed consent,(Appendix C) RD arranged a convenient time with the researcher to complete the route learning tests.

For the real world route learning test, RD was transported to the beginning of the route by car, taking care to avoid any part of the route on the way. He undertook the naturalistic baseline condition on route B (see Figure 8.2) and two weeks later undertook the distal landmark condition on route A (see Figure 8.1).

Table 8.2: Experimental procedure

Order	Baseline (naturalistic) condition	Intervention (distal strategy) condition
1	Learning trial 1: follow researcher	Learning trial 1: follow researcher
2	Test trial 1: repeat route independently (researcher follows)	Test trial 1: repeat route independently (researcher follows)
3	Five minute break	Overview of distal landmarks by researcher
4	Learning trial 2: follow researcher	Learning trial 2: follow researcher, stopping at turns with prompt to select distal landmarks
5	Test trial 2 (to account for practice effects): repeat route independently (audio recorded (researcher follows)	Test trial 2: repeat route independently (audio recorded, (researcher follows))
6	Landmark recall test (audio recorded)	Landmark recall test (audio recorded)

8.3.4.3.1 Baseline (naturalistic) condition procedure

The procedure for the baseline condition is shown in Table 8.2. This condition allowed a baseline without any landmark training to be captured (i.e. with the participant using their natural strategy) which could then be compared to the intervention condition in which the distal landmark strategy was introduced. It would be necessary to control for the effect of practice in the intervention trial and therefore, RD completed two learning trials and two test trials in the baseline condition. The second learning and test trial would therefore establish the effect of practice, so that this could be controlled for in the intervention condition.

On the first learning trial he was instructed that he should try to remember the route as he was led around by the researcher. Once back at the start of the route RD was instructed to repeat the route without guidance from the researcher (the researcher walked three to four paces behind). After a five minute break, RD was again guided around the same route by the researcher and then undertook a second test trial without help.

On each test trial the researcher walked three to four paces behind RD and noted down his decisions. If he started to walk in the wrong direction, the researcher stopped him as soon as possible and showed him the correct turning. The time taken to walk the routes and any landmarks that RD mentioned spontaneously, were also noted on a clip board. Test trial 2 was audio recorded as an additional reliability check for the written notes. It was decided not to ask RD to point out any landmarks he was using in this condition, as the aim was to capture a genuine baseline and to do so may have unintentionally introduced a strategy that RD did not normally use.

8.3.4.3.2 Intervention (distal strategy) procedure

This condition was carried out on route A (Figure 8.1). Similar to the baseline condition, RD was driven to the beginning of the route and completed the first learning and test trial to establish a route learning score without any distal landmark training (see Table 8.2). After these were completed, the researcher pointed out some distal landmarks and explained that they are seen in the distance and stand out (like a tall building) and they are not likely to move (unlike a car). It was explained that these were different from landmarks which were close by and because they are in the distance, the same landmark may often be seen at different points along the route. It was also explained that they may be helpful and give useful cues if he got lost or forgot which way to turn. The participant was then asked to describe or point out some examples of distal landmarks to ensure the concept was understood.

The second learning trial then ensued but on this occasion, RD was asked to point out distal landmarks along the route (a minimum of one per turning) whilst following the researcher. Any proximal landmarks that were also pointed out were noted down and RD was then prompted to look for distal landmarks e.g. “Remember we are looking for distal landmarks. Distal landmarks are things you can see in the distance that stand out to you”. Once back at the beginning of the route RD embarked on the test trial, all route decisions were again noted down by the researcher and any remarks he made were captured on the audio recorder.

8.3.4.3.3 Landmark recall

RD was asked to spontaneously recall as many landmarks as he could at the end of the second test trials in both the baseline and intervention conditions. Landmark recall was recorded so that the number and types of landmarks recalled could be compared in the baseline and intervention conditions. It was also hoped that this would provide an indication of whether the landmarks that had been selected by RD during the distal learning trail had been encoded and so may have been used during the distal test trial to help him recall the route. This was completed at the end of the trials so as not to interfere with his strategy or to effect his concentration during the task.

8.3.4 Results

Table 8.3 shows that RD made more wrong turns on trial 2 of the baseline condition. Interestingly, one of his route recall errors on test trial 2 was new, one was the same error that he made during test trial 1 and another was one that he had spontaneously corrected himself on test trial 1 (i.e. on Test trial 1 he had started to go the wrong way and corrected himself so this was not scored as an error). In the intervention condition he obtained a maximum score after the introduction of the distal strategy and he recalled one additional landmark.

RD's choice of landmarks during the distal learning trial is shown in Table 8.4, together with the landmarks he recalled after the distal test trial. Despite the explanation and demonstration of distal landmarks, RD frequently chose proximal landmarks during the distal learning trial (eight in total). He also selected landmarks that would not be permanent (i.e. three cars and two vans) and therefore allowing him free choice would not necessarily result in the best strategy long term. He was however, able to select distal landmarks (six in total) when prompted, and in fact was observed and heard to use one of these at a point on the route recall when he was uncertain about which turning to take (the street lamp still switched on). Subsequently, when asked to recall landmarks, he was able to recall four but this did not include the landmark that had helped him on the recall trial.

RD walked the route very quickly, it took him 12 to 13 minutes to complete each test trial. In fact he walked so quickly that the researcher had difficulty keeping up with him. The quality of the audio recording was poor due to this and also due to traffic noise. RD was enthusiastic about the study and very willing to look for distal landmarks but, as noted above, he did not naturally choose these. At the end of the study, RD reported that pointing out landmarks generally, during the learning trial had helped him recall the route but it was clear that he was not differentiating between a proximal-based landmark strategy and a distal-based strategy.

Table 8.3: Results of the route learning and landmark recall tests for RD and BS

	Baseline			Intervention		
	Test trial 1 Correct turns*	Test trial 2 Correct turns*	Landmarks recalled	Test trial 1 (no strategy) Correct turns*	Test trial 2 (distal strategy) Correct turns*	Landmarks recalled
RD	14	12	3	13	15	4
BS	13	13	0	13	15	4

**maximum score = 15*

Table 8.4: *Landmarks chosen by participants during the distal training trial and whether they were recalled after testing*

		BS				RD	
Landmark	Proximal or distal	Pointed out during learning trial	Recalled post-test	Landmark	Proximal or distal	Pointed out during learning trial	Recalled post-test
Café	P & D	No	Yes	For sale signs	P	Yes	No
Chip shop	P	No	Yes	Red notice board	P	Yes	No
Factory	D	No	Yes	End of bike lane sign	P	Yes	No
Boxing gym	D	No	Yes	House that looks like a castle	P	Yes	No
				Upside down bin	P	Yes	No
				BMW with no number plate	P	Yes	No
				Yellow car	P	Yes	No
				Silver car	P	Yes	Yes
				Shops in the distance	D	Yes	No
				Pylons	P & D	Yes	Yes
				Street lamp still switched on	D	Yes	No
				Two white vans	D	Yes	Yes
				Building with people leaving	D	Yes	Yes
				House that looks like Headway	D	Yes	No
				Give way sign	D	Yes	No

8.3.5 Discussion of Case Study 1

The results of the neuropsychological testing suggested that RD had difficulty with verbal long term memory and spatial working memory. Given that he left school without qualifications, this may however, be in keeping with his premorbid functioning. However, this this cannot be assumed for certain in the absence of a test of premorbid function. There was no indication of any visual deficit or nominal aphasia that could affect his performance in the current study. On the virtual reality route learning test he had shown a relative deficit when only distal landmarks were available and therefore, was felt to be a suitable candidate for a study which would explore whether supplementing his natural approach to route learning with a distal landmark strategy would be helpful.

RD's score on the first test trial of both conditions was very high suggesting little room for improvement. However, his errors increased on Test 2 of the baseline condition, seemingly because he repeated his errors. This confirms the need to take an errorless learning approach to route learning as suggested by Lloyd et al. (2009b). This trial was included in order to control for the effect of practice in Test trial 2 of the intervention condition and suggests that at least in RD's case, practice effects were not in issue, although this could well be an anomaly in his case. In the intervention condition, after the distal landmark training (Test trial 2), RD remembered two additional correct turns, taking him to the maximum score for this test. Overall, together with his comments, this provides some anecdotal evidence that the additional strategy was helpful to RD although it may have cued him in to using landmarks generally, rather than distal landmarks per se.

An exploration of his landmark use and recall (Table 8.4) shows that he was able to identify distal landmarks albeit not consistently, as 8 out of 15 were proximal. However, he only recalled four landmarks after distal training (one more landmark than he had in the baseline condition) and two of these were distal, one was proximal and one could be classed as proximal or distal. Ironically, he did not recall the distal landmark that had helped him when he was uncertain which turn to take, which suggests that landmark recall may not be an appropriate measure of whether a landmark that was selected, was actually used.

8.4 Case study 2

BS was recruited using the same recruitment process as RD, but from a local day centre rehabilitation service rather than Headway. He was also 38 years old and had sustained a TBI 15 months prior to the study. He had fallen from a roof whilst completing some building work. Self-report and available notes from the rehabilitation centre suggested a severe TBI with a period of coma, a stay in a local acute hospital and attendance at the local day centre rehabilitation service. BS left school at 16 without any qualifications and had worked at a local factory before starting work in his family hospitality business. At the time of testing BS had just finished attending the rehabilitation centre and was working part-time in his family business. He had used local patient transport services provided by the hospital or private taxis to travel to the centre and travelled with family locally on routine trips but did not travel alone. Staff at the centre and BS reported difficulty with wayfinding and learning new routes.

8.4.1 Procedure

BS had not taken part in the study described in Chapter 7 and so the screening tests were administered in a separate session prior to the baseline condition. Otherwise, the procedure was the same as RD, except that the order of routes was reversed i.e. his baseline (naturalistic) condition was in route A.

8.4.2 Results

8.4.2.1 Neuropsychological tests

BS scored below the first percentile (impaired range) on the AMIPB list learning test, ‘average’ on the delayed recall (39th percentile), ‘below average’ on the WMS-IV spatial addition sub test (9th percentile) and ‘below average’ on the WMS-IV symbol span test (16th percentile).

8.4.2.2 Landmark recognition

BS obtained a maximum score of five out of five on the landmark recognition task. This suggests that he did not suffer from landmark agnosia, was able to create whole percepts of landmarks and could name the landmarks.

8.4.2.3 Virtual reality route learning test

In the proximal landmark condition BS scored 12 out of 15 for the VR route recall test and in the distal condition he scored 3 out of 15. In the proximal condition he recalled 6 landmarks but in the distal condition he was not able to recall any landmarks. Thus, BS showed a relative deficit in VR when only distal landmarks were available, compared to when only proximal landmarks were available.

8.4.2.4 Real world route learning test

Table 8.3 shows that in the baseline condition, BS scored thirteen out of fifteen on both test trials. In the intervention condition BS scored thirteen in the first test trial and this increased to a maximum score of fifteen in the second test trial, after he had undergone distal training and been asked to point out distal landmarks. He did not recall any landmarks in the baseline condition but he recalled four in the intervention condition after distal landmark training (two proximal and two distal).

BS frequently reported that he found the task tiring and he took between 13 to 14 minutes for test trials. He stated that his approach to route learning was to “just walk”. He found it difficult to engage with the task of pointing out distal landmarks and in fact was unable to select any. When asked to do this, he said that he was afraid that using a strategy whilst walking the route might distract him from his successful walking strategy and felt that it would reduce his overall performance on the test.

It can be seen from Table 8.4 however, that despite not being able to point out any distal landmarks in the distal learning trial, BS did spontaneously recall two during the landmark recall test, together with two proximal landmarks. He told the researcher that he noticed the boxing gym sign because he enjoyed watching boxing and he noticed the factory because he used to work in a factory that looked similar to it.

8.4.3 Discussion of Case Study 2

The results of the neuropsychological tests suggest that BS had some difficulty with verbal learning but was able to learn with repetition. In the absence of a premorbid test of function it is unclear how his neuropsychological test scores compare to his premorbid performance. His performance on the virtual reality route learning tests showed that he had a relative deficit in the distal condition and so would be a suitable candidate for the current study.

Despite the fact that BS found selecting distal landmarks difficult and was reluctant to engage in the strategy, his performance did improve after distal landmark training, whereas it had remained static in the baseline condition. Of further interest is the fact that after the distal learning trial, BS spontaneously recalled two distal landmarks that he had a personal interest in, despite not having pointed them out during learning. This supports the importance of the concept of landmark salience (Chan et al, 2012), and corroborates the suggestion that landmarks are more effective for navigation if they are self-selected (e.g. Bouwmeister et al., 2014).

8.5 General Discussion

The current study aimed to explore whether two participants with TBI who had a demonstrable deficit in route learning using distal landmarks in VR, were able to select distal landmarks in the real environment in order to use them to supplement their natural route learning strategy. It also aimed to establish whether there was anecdotal evidence that the approach might be effective and whether recommendations for the design of a feasibility study could be made.

With regard to whether the two participants were able to select distal landmarks, this was variable. Although RD was able to do this when prompted, he frequently reverted to proximal landmarks. Furthermore, because cars were salient to him, he focussed on these, even though they would not be an efficient strategy in the long term. He was however, willing to try a distal strategy and was keen to learn. Therefore, RD may be able to adopt the approach after a more extended period of training and/or with support to pick out appropriate distal landmarks during training. The approach was not acceptable to BS but this was not necessarily related to difficulty identifying distal landmarks, his concern seemed to be that any strategy adopted whilst learning might impact upon his own natural approach. This highlights the fact that for compensatory strategies in general to be adopted, they must be acceptable and meaningful to the individual (Baldwin, Powell & Lorenc, 2011). Furthermore, his performance is likely to have helped to maintain his belief that his own strategy was effective because he made so few errors and he is unlikely to have travelled frequently enough on his own (as reported by BS and by keyworkers), to appreciate the serious consequences of making one wrong turning, which could result in becoming completely lost.

With regard to any indication that the strategy was beneficial, RD's route performance deteriorated in the naturalistic baseline condition but improved after distal strategy training. BS's performance was static in the baseline and improved after distal strategy training. Thus, in the absence of any indication of practice effects, there is some slight indication of improvement in the intervention trial. It is however, impossible to attribute this effect to the distal landmark training based upon two uncontrolled case studies, particularly in the case of BS, who may not have consciously and actively engaged with the strategy at all.

In retrospect, the notion that spontaneous landmark recall could give an indication of whether landmarks that had been pointed out during training were used during route recall, was an incorrect assumption. This may be consistent with the suggestions that some aspects of route recall may rely on implicit processes rather, than explicit for both learning and recall (Brooks et al., 1999; Evans et al., 2000). This appeared to be the case for RD who clearly benefited from at least one distal landmark even though he did not recall it. In addition, BS had encoded at least two distal landmarks without pointing them out during the route. A recognition memory task or a map recognition test as described by Sorita et al. (2012) might be a more suitable option but this would be very difficult in a real world environment. Particularly as there are so many landmarks in the real world that it may not be possible to anticipate which would be chosen.

It is also important to consider the ecological validity of the VR tests to determine which landmarks were taught in these real world case studies (i.e. proximal or distal). The VR test used in the current study was tested on a small number of participants (see Chapter 7) and it is important to note that these findings may not be generalizable to the wider population. As previously discussed (see Chapters 4 & 6), VR studies may not fully capture all cues which are available in the real world (Taube et al., 2013), but numerous studies support the equivalence of route learning in VR and the real world (Lloyd et al, 2009a) and the transfer of training from the virtual to the real world (Brookes et al., 1999; Darken & Banker, 2008; Farell et al., 2003; Sorita et al., 2012; Wallet et al., 2009). The VR test used did support previous work which suggested that people with TBI may have difficulty navigating using distal landmarks (Livingstone & Skelton, 2007) and using VR also allowed for the experimental manipulation of the environment in a route learning task to explore this in a way which was not possible in the real world. Specifically, most environments contain a mixture of both proximal and distal landmarks and there is no way to remove or hide each type of landmark from view in order to assess whether route learning is impaired in the absence of each landmark type. The recommendations for further research to collect more data and develop a set of norms for the VR test (Chapter 7) may seek to address this issue in the future.

8.6 Recommendations for a feasibility trial

The National Institute for Health Research (as cited in Shanyinde, Pickering & Weatherall, 2011, p. 1) define feasibility studies as "… pieces of research done before a main study to answer the question 'Can this study be done?'" and they are used to test parameters before a main study is designed or carried out. The case studies presented, are perhaps just one step along the path to a feasibility trial in that they have highlighted some areas that require further consideration. These considerations are noted in Table 8.5.

8.7 Conclusion

Overall, the current case studies suggest that it would be beneficial to embark on a feasibility study, incorporating the recommendations in Table 8.5. One aspect that may require further consideration however, is the fact that by encouraging RD to look for distal landmarks, it also inadvertently facilitated his identification of proximal landmarks too, which may also explain the improved recall.

Overall, the case studies certainly suggest that a focus on landmark identification may be a feasible intervention for people with TBI who do not have landmark/topographical agnosia, although a randomised control trial is needed to explore efficacy. The focus on landmarks provides a less complex and more practical solution than some of those described in the introduction, such as the use of PDAs described by Sohlberg et al., (2007) and Liu et al., (2008). It is also more generalisable and may be more socially acceptable to patients than using a checklist as trialled by Newbigging and Laskey (1996), as participants may be deterred from using memory strategies which remind them that they are different from others or prefer to rely on their own memory, rather than on memory aids (Baldwin et al., 2011).

Furthermore, by supplementing the natural use of proximal strategies with a distal strategy it may facilitate navigation if routes that have been acquired using a purely allocentric strategy are no longer available (Doeller et al., 2008), thus facilitating a more flexible wayfinding style (Bohbot et al (2004). Finally, it is important to develop strategies that are model-driven, rather than attempting approaches through trial and error and it is hoped that the findings described here go some way to providing such a landmark-based model.

Table 8.5: *Considerations from the current study and recommendations for a future feasibility trial*

Lessons learned from case studies	Recommendation
The use of a real world route meant that participants with TBI had to be independently mobile and safe, as judged by therapists and care workers. Other factors that had to be considered were: mobility, fatigue, visual problems, balance, safety crossing roads and anxiety. Staff at one of the local Headway centres stipulated that due to a duty of care to their clients, all trips from the centre should be accompanied by a care worker who had received health and safety training. As a charitable organisation, Headway provides a number of services with limited public funding and therefore, availability of staff to accompany the trips was restricted and this impacted on the time taken to complete the study.	Allow at least 10 months for recruitment of 10 participants. Consider using Headway as a recruitment site, with prior agreement that participants who had given informed consent, would then speak directly to the researcher regarding the study. Specify that the University are sponsors of the research and explain liability and responsibility procedure to Headway.
Participants were close to ceiling on the route test trials which could lead to a lack of sensitivity in the outcome measure and suggests that more turnings are required along the route. However, extending the length of the route would not be wise	One possibility would be to find an environment with more turns across a shorter distance, although the areas and walking routes in the present study were specifically chosen to include as many turns as possible over a short distance and were very difficult to

as this could create a problem with fatigue, as experienced by BS during the current study.	find in a real world setting. An alternative could be to carry out the i) the entire study in a VR environment or ii) carry out the training sessions in VR to minimise the amount of time walking the routes. The VR element may allow for more standardised training to be implemented and greater experimental control.
Despite repeating the route with minimal errors, both participants recalled surprisingly few landmarks. This could lead to a 'floor effect' in future trials.	A recognition memory test would perhaps resolve the 'floor effect' but, as noted above, would be very difficult to implement in a real world setting. Nor would it provide evidence that landmarks were used when retracing the route. This most parsimonious solution would be to ask participants to stop at each turn on the test trial and describe why they were choosing their direction of travel. This could be audio recorded using a smartphone with an earpiece or other method that participants find acceptable. A similar procedure would need to be adopted in the test trial of the baseline condition.
RD had to be prompted to select distal landmarks and often chose proximal instead.	A longer training period with additional practice could help to consolidate the distal strategy. A suitable break during the baseline condition would need to be introduced for control purposes.

RD frequently chose landmarks that were not permanent and therefore, would not always be helpful during everyday life.	Given other studies in people with ABI suggest similar difficulties with selection of landmarks, e.g. Bouwmeester et al (2015), an approach that involves a choice between a range of landmarks might be the most parsimonious solution if the environment allowed it, with an emphasis on stable landmarks, visible from decision points and in the direction of travel (Baumann, Chan, & Mattingley, 2012; Janzen, 2006; Röser et al., 2012). Alternatively, practice in VR using different landmark approaches to demonstrate the advantages of different types of landmarks and also to consolidate training in the use of distal landmarks might be helpful.
The audio recording had poor sound quality	Although it was possible to mark errors made along the route taken by participants using a checklist, it was very difficult to record vocalisations that would give insights into spontaneous strategy use. In addition, asking participants to verbalise their thought processes during recall may interfere with the implicit nature of the task and potentially reduce route recall. A more efficient system of recording interactions would therefore be necessary e.g. including a wearable sound recorder which is specialised for outdoor use, if participants would tolerate this.

CHAPTER 9

GENERAL SUMMARY

In the process of writing this thesis, three things became evident. Firstly that there was no comprehensive large scale study of changes in travel patterns after ABI; secondly, there is a dearth of models on which to base rehabilitation strategies for wayfinding and route learning; and thirdly there is a need for an ecologically valid task to measure these skills.

The aim of this thesis was to explore community travel and route learning in people with acquired brain injury through a questionnaire study and a series of studies using VR. VR has been already been shown to offer an ecologically valid way of testing everyday route learning skills and has shown equivalence with real world performance (e.g. Lloyd et al., 2009a; Lloyd et al., 2009b).

The first study in this thesis explored changes in community travel patterns after ABI and found that over 70% of people reported a general reduction in all types of journeys, particularly those carried out alone and for leisure purposes. Despite the fact that earlier small scale/qualitative studies had suggested a major role for anxiety in this relationship, it only played a small part in the reported reduction in travel and so its role was not as great as expected. Participants reported other reasons for the reduction in travelling such as no longer having reasons to travel because they no longer worked or had fewer friends. Not returning to driving was also frequently reported by participants, indicating that this was one of the most commonly used modes of transport pre-injury. Research by Logan (2004) and Rosenkvist et al. (2009) suggests that individuals report alternative means of transport such as using the bus, are a particular challenge.

Interestingly, based upon a general question about the frequency of post-injury travel compared to pre-injury, regression analyses suggested that anxiety made a unique and significant contribution to the reduction in travel but disability did not. When exploring specific types of journey however, the picture was reversed; in those journeys that returned a significant regression model (unaccompanied journeys and journeys associated with leisure activities), anxiety was not a significant predictor, whereas a higher level of disability was associated with a greater reduction in travel. When demographic variables were explored, being older was significantly associated with the reduction in three types of journey (unaccompanied, routine and leisure). This is perhaps not surprising given that an association between older age and worse functional outcome has often been demonstrated after traumatic brain injury (Hukkelhoven, Steyerberg, Rampen, Farace, Habbemma et al., 2003). The only other demographic variable that predicted a change in travel was educational achievement, with those who had a higher level of attainment showing a greater reduction in leisure trips. Further research is therefore needed to explore the impact of other factors such as education and the changes in social networks.

Chapter 3 leads us to another theme that is woven throughout this thesis, which is the need for an ecologically valid test of wayfinding that can be used by rehabilitation staff to assess route learning and navigational skills. This could be applied in the early stages of injury before any anxiety-related avoidance appears. Thus, the VR route that was developed for this study, could be investigated and developed further in order to address this issue.

The reduction in community travel did, however, impact on quality of life, further emphasising the need to address this in rehabilitation programmes. As well as overcoming the physical and emotional barriers to travel, the cognitive deficits associated with route learning also need to be addressed in rehabilitation. Thus the next chapters focused on exploring the use of landmarks for route learning in an attempt to explain the difficulties encountered by those with TBI and to begin to explore a model-driven rehabilitation strategy that would be helpful.

To date, most reports of attempts to rehabilitate navigational skills and route learning in people with ABI have been anecdotal. Only one group of researchers (Skelton and colleagues) has explored this issue in depth. These studies focussed on place learning and involved the use of a virtual MWM. This thesis builds on their work in two ways; it extends their findings to route learning and uses a more ecologically valid task. Landmarks were chosen as the focus for this study because they feature in over half of the anecdotal reports of rehabilitation attempts in the literature and are a key factor in acquiring route knowledge.

In order to investigate the use of proximal and distal landmark-based strategies in route learning after ABI, a new virtual reality environment was created. The justification for using VR is based upon its capacity to mimic the real world, thus bringing us closer to ecological validity; its controllability compared to the real world;

and the developing evidence base that supports transfer of learning and generalisability to the real world. First, a pilot study was conducted that assessed the suitability of four different gaming controllers for use by relatively inexperienced game users including those with ABI. It transpired that using a controller did not present any difficulty for people with ABI, with the joystick being the preferred option. Two virtual routes through a virtual town were developed and tested in a pilot study and were found to be equivalent in difficulty and therefore suitable for use in the main route learning study. The development of the routes was carried out by the researcher herself. This involved learning how to use a variety of technical information and the use of two virtual software design packages and took up a substantial amount of time during the period of study. It is hoped that these routes will ultimately be available for piloting and developing further as rehabilitation tools/assessments to the rehabilitation service that funded this thesis.

Building on the work of Skelton's group, the VR study explored whether people with TBI performed better if only proximal or distal landmarks were available during route learning. Results were mostly in keeping with those found for place learning by Skelton and colleagues in that people with TBI appeared to be differentially affected in the distal condition (they also performed worse than neurologically intact controls overall). This finding is in keeping with the current evidence base that suggests the hippocampus, which may be particularly vulnerable to damage after TBI (Atkins, 2011; Kotapka et al., 1992; Mañeru et al., 2005; Tate & Bigler, 2000; Tomaiuolo et al., 2004), is important for learning and navigating routes through the use of cognitive maps. Such maps are based upon an allocentric strategy (rather than egocentric) and rely to a large extent on the use of distal landmarks to supply directional information (Burgess et al., 2002; O'Keefe & Nadel, 1979; Elkstrom et al., 2003). Other measures, i.e. map drawing and landmark recall, were also used to explore recall of routes as well as navigating the routes in VR per se. These measures confirmed that people with TBI performed worse overall, but they did not show the same differential effect in the distal condition. It is not clear why this was the case but it was clear that people with TBI found the map drawing task difficult, and this showed a slight floor effect, which may have undermined the statistical analysis. Self-reported strategy use proved to be a useful adjunct to the study (although some items on the questionnaire also suffered from floor effects), in that it confirmed that the routes had the necessary impact (i.e. forced use of either the distal or proximal strategy) and it also provided preliminary evidence to support the difficulties experienced by people with TBI in making use of distal landmarks to derive directional information.

Given that people with TBI performed better on the VR route learning task using proximal landmarks, the final study described two case studies in which participants with TBI who showed a deficit in learning routes in VR when only distal landmarks were available, were helped to select distal landmarks to supplement their natural approach to a real world route learning task. Useful lessons for a future feasibility study were also learned e.g. it was clear that expecting participants to choose their own suitable proximal and distal landmarks was not realistic and a supported choice would need to be provided by therapists. Also, participant recruitment was considerably challenging and alternatively, designs involving VR could be considered in future research to overcome problems with mobility and fatigue. Overall, the case studies suggest that a focus on landmark identification may be a feasible intervention for people with TBI who do not have landmark/topographical agnosia, although a randomised control trial is needed to explore efficacy in real world route learning in people with TBI.

In summary, this thesis adds to the literature in several important ways. It provides the first profile of the nature of changes in community travel after ABI in a large group of participants. It highlights the importance of addressing community travel in rehabilitation, as a reduction in community travel may impact on quality of life, further emphasising the need to address this before individuals return to their daily lives, perhaps even using VR if people are not yet mobile or too anxious to travel. The studies reported herein also begin to provide a landmark-based cognitive model on which rehabilitation strategies for route learning can be based and a means to explore this model in a larger study. It also makes a practical contribution to the field in that, in the future, the VE will be made available for piloting clinically, at a local rehabilitation service as an ecologically valid measure of route learning and hopefully developed further.

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See Appendix G for 3D model references

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Appendices

Appendix A: Ethical approval for the research

ETHICS AMENDMENT

Appendix B: Participant Information Leaflets

Chapter 3

A questionnaire investigating community travel after an acquired brain injury

Introduction
My name is Laura Nice and I am a PhD research student at the University of Birmingham. I am supervised by Dr Theresa Powell, who is a clinical psychologist and a lecturer at the university and we would like to invite you to take part in a study.

What is the study about?
The study is about community travel after an acquired brain injury. It is common after a brain injury for people to experience changes in patterns of community travel e.g. how often you make a short journey to the shops by yourself or how you feel about making this journey. Research suggests that changes in community travel may be related to your quality of life or general wellbeing and we would like to explore this area by using a questionnaire.

What will I have to do?
You will be invited to complete a questionnaire which will take about 20-25 minutes. You will be asked a series of questions about the following areas:

- Some short questions about you e.g. your education, basic details of your injury.
- The amount of assistance you receive to complete daily tasks e.g. doing the housework, getting shopping.
- How satisfied you are with different areas of your life e.g. at home, your health.
- Current travel outside of the home e.g. changes in travelling patterns since your injury, how you feel about travelling by yourself.

If you decide to take part, the researcher will bring the questionnaire to the rehabilitation centre, read out the questions with you and write down your answers.

What are the benefits?
There may not be any benefits to you directly but in the future, we hope this research will help inform rehabilitation by gaining a better understanding of community travel after a brain injury.

What happens to the information?
The information will be completely confidential and will be coded. This means that your name will not appear with your data. There is a university requirement to keep date for 5 years from the point of publication. Your name will not be used in any publications.

What if I change my mind during the study?
You are under no obligation to take part. If you decide not to take part at any point during the questionnaire, this will not affect any aspect of your current treatment. You are free to withdraw from the study at any point until the study is published and your data will be destroyed.

What if something goes wrong?
It is very unlikely that something could go wrong. However, the researchers are indemnified by the University of Birmingham. It is very unlikely that something could go wrong. However, the researchers are indemnified by the University of Birmingham. If you wish to speak with someone who is NOT involved in the research about any issues raised you may contact your key worker.

What happens at the end of the study?
The data will be analysed and published as part of a thesis and also in an academic journal. A summary of the research findings will be sent to the rehabilitation service and if you would like, you may request a copy of these from the rehabilitation service.

What if I have more questions or do not understand something?
Please contact myself (Laura Nice) or Dr Theresa Powell using the contact details below. Or you can ask your key worker to contact us and we will get back to you.

What happens next if I decide to take part?
Please either let your key worker know that you would like to take part or you can contact us using the details below. We will then ask you to read and sign a consent form and we will answer any other questions you may have.

Contact details

Dr Theresa Powell
Lecturer in Clinical Psychology
University of Birmingham
Telephone: [redacted]
Email: [redacted]

Laura Nice
Psychology Postgraduate Researcher
University of Birmingham
Telephone: [redacted]
Email: [redacted]

Chapter 7

An investigation into the use of proximal and distal landmarks for virtual route learning

Introduction

My name is Laura Nice and I am a PhD research student at the University of Birmingham. I am supervised by Dr Theresa Powell, who is a clinical psychologist and a lecturer at the university and we would like to invite you to take part in a study.

What is the study about?

The study is about how people learn a route after they have had a brain injury. It is common after a brain injury for people to have physical or cognitive difficulties (e.g. learning or memory problems). There are a number of different ways to help people learn a route during rehabilitation. We feel that the way in which you learn a route may make a difference and so we want to compare two different approaches.

What will I have to do?

You will be invited to attend two sessions and these are explained below.

Session 1: At the Rehabilitation Centre/University (60 minutes)

- Answer some short questions about you e.g. your education and basic details about your injury.
- The researcher will read out instructions and ask you to complete some tests relating to areas of learning and memory. This will involve trying to remember some words, pictures and location of objects, watching a short video of a route and trying to remember it.
- You will also be asked how you feel about trying to remember the route from the video.

Session 2: At the Rehabilitation Centre/University (60 minutes)

In this session you will use a joystick to move around a virtual route displayed on a computer screen. You will be given instructions on which way to go. Once you have gone around the same route 3 times, you will be taken back to the start point and asked to go around the virtual route again without using the instructions. If you start to move in the wrong direction at any point on any of the trials, the researcher will bring you back to the correct point. The researcher will note down which way you turn and ask you why you chose to go that way. The researcher will also ask how you feel about walking the route without the instructions.

What are the risks?

Every effort has been made to minimise the risks involved in this study and we will ensure your therapists are happy that the task is safe for you to perform.

There are no bright or flashing images in the study but if you have suffered any adverse effects when viewing a television screen, you may not wish to volunteer.

What are the benefits?
There may not be any benefits to you personally but there is a possibility that it *may* help your therapists decide the best way to help you learn as part of your rehabilitation. In the future we hope this research will help us decide the best way to help other people learn and remember routes themselves.

What happens to the information?
The information will be completely confidential and will be coded. This means that your name will not appear with your data. There is a university requirement to keep date for 5 years from the point of publication. Your name will not be used in any publications.

What if I change my mind during the study?
You are under no obligation to take part. If you decide not to take part at any point during the study, this will not affect any aspect of your current treatment. You are free to withdraw from the study at any point until the study is published and your data will be destroyed.

What if something goes wrong?
It is very unlikely that something could go wrong. However, the researchers are indemnified by the University of Birmingham. If you wish to speak with someone who is NOT involved in the research about any issues raised you can contact your key worker or the PALS Moor Green Advice and Information Officer: Joan Walker-Fearon, West Midland Rehabilitation Centre, 9 Oak Tree Lane, Selly Oak, B29 6JL, Telephone: [redacted]

What happens at the end of the study?
The data will be analysed and published as part of a thesis and also in an academic journal. If you would like, you will be given a copy of the results of your tests and you will be sent a summary of research findings.

What if I have more questions or do not understand something?
Please contact myself (Laura Nice) or Dr Theresa Powell using the contact details below. Or you can ask your key worker to contact us and we will get back to you.

What happens next if I decide to take part?
Please either let your key worker know that you would like to take part or you can contact us using the details below. We will then ask you to read and sign a consent form and we will answer any other questions you may have.

Contact details
Dr Theresa Powell
Lecturer in Clinical Psychology
University of Birmingham
Telephone: [redacted]
Email: [redacted]

Laura Nice
Psychology Postgraduate Researcher
University of Birmingham
Telephone: [redacted]
Email: [redacted]

Chapter 8

An investigation into the transfer of route learning from the virtual to the real world

Introduction

My name is Laura Nice and I am a PhD research student at the University of Birmingham. I am supervised by Dr Theresa Powell, who is a clinical psychologist and a lecturer at the university and we would like to invite you to take part in a study.

What is the study about?

Sometimes people can experience physical or cognitive difficulties after a brain injury which may affect how they learn or remember things. This study is about learning and remembering a route from one place to another e.g. a particular path from a street to a shop. Research suggests that we can learn a route when using a computer, just as well as walking a real route ourselves. We would like to explore this by looking at differences between learning a virtual route on a computer and learning a real route on real streets.

What will I have to do?

You will be invited to attend two sessions and these are explained below.

Session 1: At the Rehabilitation Centre (30 minutes)

- Answer some short questions about you e.g. your education and basic details about your injury.
- The researcher will read out instructions and ask you to complete some tests relating to areas of learning and memory. This will involve trying to remember some words, pictures and location of objects, watching a short video of a route and trying to remember it.
- You will also be asked how you feel about trying to remember the route from the video.

Session 2: At the Rehabilitation Centre and a route near the rehabilitation centre (1 hour)

You will complete a LEARNING session and a TEST session. The researcher will ask you to complete the learning session either on a computer or on real streets. The test session will always take place on real streets, close to the rehabilitation centre, Birmingham.

LEARNING: In this session you will be asked to go around a route several times. If you are completing the computer session, you will sit in a room at the rehabilitation centre and use a joystick to move around a virtual route displayed

Note. This participant information leaflet was from a transfer study that was not included in the thesis but was granted ethical approval as part of the main study. An ethics amendment was submitted (Appendix A) to include the 'follow-up' section, which was used in Chapter 8.

on a computer screen. If you are completing the real world session, you will walk around real streets.

In both sessions you will be given a sheet with written directions telling you which way to go. The instructions will be based on obvious landmarks or objects which you will be able to see from where you are standing. An example of an instruction might be “please walk towards the red post box in front of you” or “walk to the traffic lights at the end of the road”. You will be given a pen and asked to put a tick next to each instruction once you have completed it.

TEST: Once you have gone around the same route 2-3 times, you will be taken back to the start point and asked to walk the route again but without using the instructions. If you start to walk in the wrong direction at any point on any of the trials, the researcher will bring you back to the correct path i.e. you will not be able to get lost. The researcher will note down which way you turn and will ask you why you chose to go that way. The researcher will also ask how you feel about walking the route without the instructions.

Follow Up

A small number of participants (2 or 3) will be asked to take part in a follow up from our original study. This will involve completing both real world tests and a virtual test on the computer in the same way and in the same places as described above. This will involve going to two real world routes with the researcher. We hope this will allow us to see whether you can use a strategy to learn a route in the real world. This means:

Sessions 1 & 2: Virtual landmark test – complete two virtual reality landmark tests where you will be asked walk around two virtual routes on a computer, whilst you are at the rehabilitation centre. Then you will be asked to try and remember the routes you have seen

Session 3: Real world route learning test – complete a real world route learning test (as described above on page 1).

Session 4: Strategy session – you will be asked to go another real world route with the researcher again and the researcher will either direct you around the route by pointing out certain landmarks or just ask you to walk the route again.

What are the risks?

Every effort has been made to minimise the risks involved in this study and we will ensure your therapists are happy that the task is safe for you to perform. The real routes will take about 10 minutes to walk around. They are located in a quiet, residential suburb of Birmingham, near to the rehabilitation service in Moseley. You will be asked to walk around the route at a speed that is comfortable for you and can stop or take a break whenever you need to. The maximum number of times any person will walk a route is four. If you are not able to do this (with breaks), then you may not wish to volunteer. There are no bright or flashing images in the study but if you have suffered any adverse effects when viewing a television screen, you may not wish to volunteer.

What are the benefits?

There may not be any benefits to you personally but there is a possibility that it *may* help your therapists decide the best way to help you learn as part of your rehabilitation. In the future we hope this research will help us decide the best way to help other people learn and remember routes themselves.

What happens to the information?

The information will be completely confidential and will be coded. This means that your name will not appear with your data. There is a university requirement to keep data for 5 years from the point of publication. Your name will not be used in any publications. With your permission, we may obtain basic details of your injury only from your medical notes.

What if I change my mind during the study?

You are under no obligation to take part. If you decide not to take part at any point during the study, this will not affect any aspect of your current treatment. You are free to withdraw from the study at any point until the study is published and your data will be destroyed.

What if something goes wrong?

It is very unlikely that something could go wrong. However, the researchers are indemnified by the University of Birmingham. If you wish to speak with someone who is NOT involved in the research about any issues raised you can contact your key worker or the PALS Moor Green Advice and Information Officer: Joan Walker-Fearon, West Midland Rehabilitation Centre, 9 Oak Tree Lane, Selly Oak, B29 6JL, Telephone: [redacted]

What happens at the end of the study?

The data will be analysed and published as part of a thesis and also in an academic journal. If you would like, you will be given a copy of the results of your tests and you will be sent a summary of research findings.

What if I have more questions or do not understand something?

Please contact myself (Laura Nice) or Dr Theresa Powell using the contact details below. Or you can ask your key worker to contact us and we will get back to you.

What happens next if I decide to take part?

Please either let your key worker know that you would like to take part or you can contact us using the details below. We will then ask you to read and sign a consent form and we will answer any other questions you may have.

Appendix C: Participant Consent Form

The purpose of this form is to make sure that you are happy to take part in the above study and that you know what is involved.

Please circle YES or NO for each answer and sign below if you agree that:

- I have read and understood the participant Information leaflet *YES / NO*
- I have had the opportunity to ask questions *YES / NO*
- I agree to take part in this study *YES / NO*
- I understand that the researchers may access my medical records for information about my injury (for participants at the rehabilitation centres) *YES / NO*
- I understand that I am free to withdraw from the study at any time and that my results will be destroyed *YES / NO*

Full name (in capitals) ____

Signature ____

Date ____

Appendix D: Potential item pool for the anxiety component of the Community Travel & Anxiety Questionnaire

Journey type (part 1 of the CTA: travel subscale)	Retained after focus group 1	Retained after focus group 2	Additional information
Independent travel	✓	✓	Included in Q1,3,5,7
Assisted travel	✓	✓	Included in Q2,4,6,8
Routine trips	✓	✓	Included in Q1,2,3,4
Recreational/social Trips/leisure trips	✓	✓	Included in Q5,6,7,8
Walking	✓	✓	Included in Q1 & 2
Driving	✗	✗	Removed after focus group
Travel with family	✓	✓	Items merged
Bus	✓	✓	
Taxi	✓	✓	
Holiday trips	✓	✓	Formed part of leisure travel

Journey type (part 2 of the CTA: anxiety subscale)	Retained from focus group 1	Retained from focus group 2	Comments
Fear of getting lost/where you are going	✓	✓	Item 1 on the CTA
Forgetting purpose of trip	✓	✓	Item 8 of the CTA
Getting lost in the community	✓	✓	Overlaps with forgetting destination and way back but merged with focus group suggestion to form items 10 and 12 on the CTA
Getting lost in large buildings	✓		Overlaps with forgetting destination and way back
Expense of taxi	✓		Specific to taxi users only
Hard to ask friends for rides	×		Specific to this task only
Limits on independent travel	×		Too vague/unclear
Bus is expensive	×		Majority of clients have free bus travel
Forgetting/missing destination	✓	✓	Item 6 of the CTA
Bus schedules and changes	×		Specific to bus/train users
Bus drivers unhelpful	✓		Specific to bus/train users
Fear of asking strangers for help/talking to strangers	✓	✓	Item 5 of the CTA

Landmarks could be confused with previous trip	×		Overlaps with forgetting the way there and back
Finding items from in store	×		Specific to shopping task
Getting separated from companion	✓	✓	Focus group changed to include not having someone to ask for help as item 9 of CTA
Forgetting destination	✓	✓	Item 1 one the CTA
Following maps while driving	×		Not appropriate task
Forgetting where the car is parked	×		Not suitable for non-car drivers
Concerns about safety/injury	✓	✓	Focus group amended to concerns about illness or injury for clarity as item 7 of the CTA
Memory issues with navigation	✓	✓	Overlap with forgetting where going
Know destination	✓	✓	Used in CTA
Get of door	×		Item covered in NEADL
Navigate to pick up spot	×		Specific to public transport
Be ready and waiting	×		Specific to public transport
ID correct vehicle	×		Specific to public transport

Board vehicle	×		Specific to public transport
Pay fare	×		Specific to public transport
Secure seat	×		Specific to public transport
Ride bus	✓	✓	Changed to include all public transport as item 2 of CTA
Negotiate pick up	×		Specific to public transport
Signal stop	×		Specific to bus or train travel only
Disembark	×		Specific to public transport
Negotiate transfers	×		Specific to public transport
ID return stop	×		Merged with navigation difficulties to item 4 of the CTA
Navigate route to destination	✓	✓	Item 3 of the CTA
Check in at destination	×		Task specific

Note,: Items 10, 11 and 12 of the CTA were generated from the focus groups

Appendix E: Community Travel & Anxiety Questionnaire (CTA)

PART 1

When answering the questions, try to think about a recent month and where possible, please try to explain your answer.

1. Compared to before your injury, how often do you travel outside the home?

|-------------------------|------------------------|-------------------------|--------------------------|

a lot less	a little less	no difference	a little more	a lot more

If there has been a change, please explain why this is:

…………………………………………………………………………………………………….

…………………………………………………………………………………………………….

…………………………………………………………………………………………………….

…………………………………………………………………………………………………….

…………………………………………………………………………………………………….

…………………………………………………………………………………………………….

PART 2

How often do you make the following journeys? Please put **B** for **before** the injury and **A** for **after** the injury.

For example, how often do you watch television? (B for before injury and A for after)

|-------------------------|-------------------------|-------------------------|-------------------------|

Never	Less than one-two times a month	One-two times a month	One-two times a week	Most days

Questions

1. Walk somewhere **by yourself** along a familiar route e.g. to the corner shop or just go out for a stroll? (B for before injury and A for after)

|-------------------------|-------------------------|-------------------------|-------------------------|

Never	Less than one-two times a month	One-two times a month	One-two times a week	Most days

2. Walk somewhere **with someone else** along a familiar route e.g. to the corner shop or just go out for a stroll? (B for before injury and A for after)

|-------------------------|-------------------------|-------------------------|-------------------------|

Never	Less than one-two times a month	One-two times a month	One-two times a week	Most days

3. Travel by transport or car **by yourself** on a routine trip e.g. to the local shopping centre or the doctors (B for before injury and A for after)

|-------------------------|-------------------------|-------------------------|-------------------------|

Never	Less than one-two times a month	One-two times a month	One-two times a week	Most days

4. Travel by transport or car **with someone else** on a routine trip e.g. to the local shopping centre or the doctors (B for before injury and A for after)

|-------------------------|-------------------------|-------------------------|-------------------------|

Never	Less than one-two times a month	One-two times a month	One-two times a week	Most days

5. Travel outside your home **on your own** to socialise or for leisure e.g. go to meet a friend, go to the gym, go to a coffee shop? (B for before injury and A for after)

|-------------------------|-------------------------|-------------------------|-------------------------|

Never	Less than one-two times a month	One-two times a month	One-two times a week	Most days

6. Travel outside your home **with someone else** to socialise or for leisure? E.g. go to meet a friend, go to the gym, go to a coffee shop? (B for before injury and A for after)

|-------------------------|-------------------------|-------------------------|-------------------------|

Never	Less than one-two times a month	One-two times a month	One-two times a week	Most days

7. Travel outside your home **on your own** on a longer journey by car train or bus, e.g . to go and visit a friend or relative in another area of the country… (B for before injury and A for after)

|-------------------------|-------------------------|-------------------------|-------------------------|

Never	Less than one-two times a month	One-two times a month	One-two times a week	Most days

8. Travel outside your home **with someone else** on a longer journey by car, train, or bus, e.g to go and visit a friend or relative in another area of the country…. (B for before injury and A for after)

|-------------------------|-------------------------|-------------------------|-------------------------|

Never	Less than one-two times a month	One-two times a month	One-two times a week	Most days

PART 3

Please circle one answer on each line

Imagine that you had to take a short trip to a familiar destination **by yourself** (e.g. to your local shopping centre). Compared to before your injury, how much would you worry about:

1. Forgetting where you are going

|------------------------|-----------------------|------------------------|--------------------------|

a lot less	a little less	no difference	a little more	a lot more

2. Using public transport

|------------------------|-----------------------|------------------------|--------------------------|

a lot less	a little less	no difference	a little more	a lot more

3. Forgetting the way there

|------------------------|-----------------------|------------------------|--------------------------|

a lot less a little less no difference a little more a lot more

4. Forgetting the way back

|------------------------|-----------------------|------------------------|--------------------------|

a lot less a little less no difference a little more a lot more

5. Talking to people you do not know

|------------------------|-----------------------|------------------------|--------------------------|

a lot less a little less no difference a little more a lot more

6. Going past your destination without realising

|------------------------|-----------------------|------------------------|--------------------------|

a lot less a little less no difference a little more a lot more

7. The thought of injury or illness

|------------------------|-----------------------|------------------------|--------------------------|

a lot less a little less no difference a little more a lot more

8. Forgetting why you went there in the first place

|------------------------|-----------------------|------------------------|--------------------------|

a lot less a little less no difference a little more a lot more

9. Not having someone to ask for help

|------------------------|-----------------------|------------------------|--------------------------|

a lot less a little less no difference a little more a lot more

10. Being in a crowd

|------------------------|-----------------------|------------------------|--------------------------|

a lot less a little less no difference a little more a lot more

11. Getting fatigued or physically exhausted

|------------------------|-----------------------|------------------------|--------------------------|

a lot less a little less no difference a little more a lot more

12. People looking at you

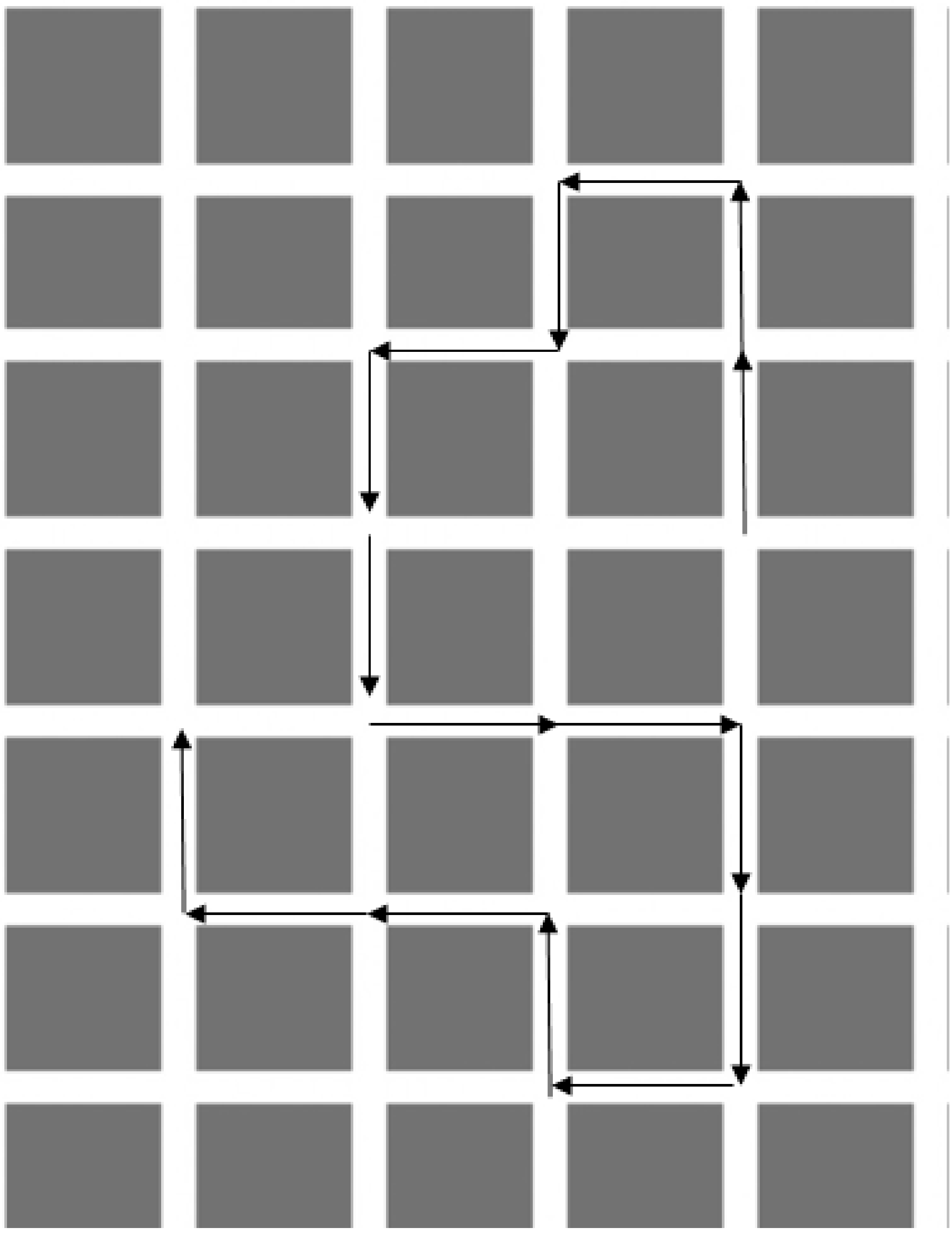
|------------------------|-----------------------|------------------------|--------------------------|

a lot less a little less no difference a little more a lot more

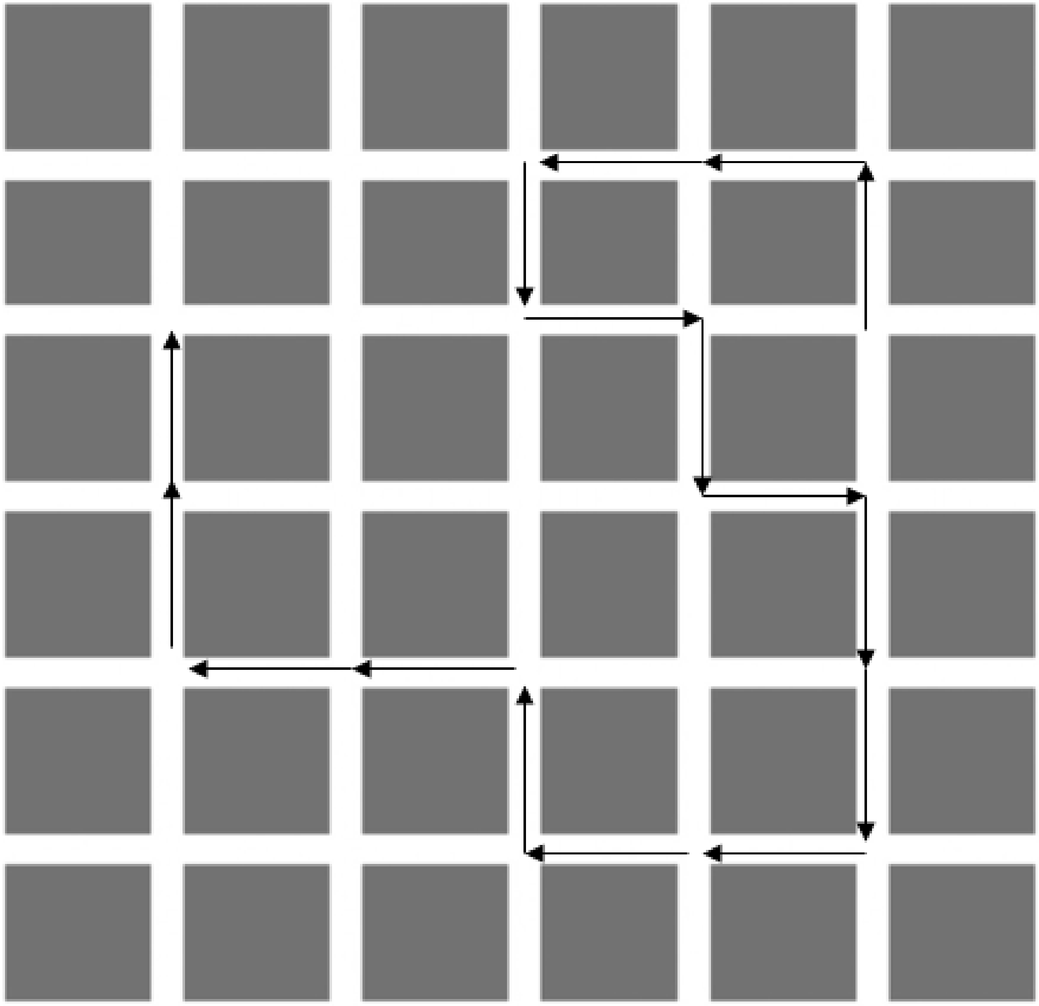
Appendix F: Route maps for the routes used in the virtual environment

---

Distal Route



Proximal Route



Appendix G: Virtual reality landmark models for the proximal and distal conditions, including references

The models below are the original models downloaded from https://3dwarehouse.sketchup.com (2012). These were modified by the research for use in the study (pictures not to scale)

Proximal Landmarks

Recycling bin

Reference: Stevie J (2013) "240 litre waste wheeler bin"; https://3dwarehouse.sketchup.com/model.html?id=d30c7f6073bb8565c8a06b09a9a18b3d (Last Accessed 16th March 2014).

Bike rack

Reference: Cyclesafe (2014). CycleSafe U/ - Rail Mount Retrieved from https://3dwarehouse.sketchup.com/model.html?id=4b763de7fcf7c5988fe3e802af0294ee (Last Accessed 10th March 2014).

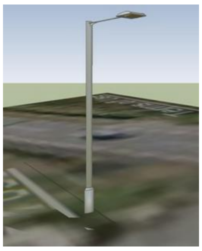
Advertising board

Reference: Tackleberry (2013). Advertising board. Retrieved from: https://3dwarehouse.sketchup.com/model.html?id=da982a1c6f88f15f9863b7bb4b024b21 (last accessed 14th April 2014)

Postbox

Reference: Mark, P (2015). British postbox: https://3dwarehouse.sketchup.com/model.html?id=ua3bbec0e-fa58-43eb-974e-e9fe80e1023b. (Last Accessed 5th January 2015).

Lamp post

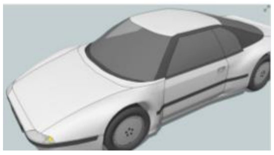


Reference: Derek, P (2012). Sconser pier lamp post. Retrieved from https://3dwarehouse.sketchup.com/model.html?id=de1e1ab82f6a7066de26d70ecaf5be71. (Last Accessed 11th March 2014).

Bollards

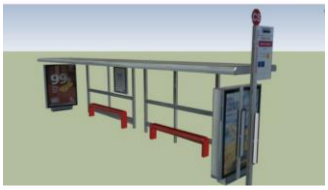
Reference: Daniel Tal. (2010). Bollards. Retrieved from: https://3dwarehouse.sketchup.com/model.html?id=505a1dc1f36de4f9680ab5641d68e6c9. (Last Accessed 9th March 2014).

Parked car



Reference: Author, A. (2009). Aerodynamic Car: Coupe 3.3i CD Prototype. Retrieved from: https://3dwarehouse.sketchup.com/model.html?id=fa1b3bcdbda309a439cc19d48e3f4f5. (Last Accessed 12th March 2014).

Bus shelter



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Pylon

Reference: KR= (2008). Power line Kallo - Zwijndrecht (Belgium). Retrieved from: https://3dwarehouse.sketchup.com/model.html?id=bb6cb9938bc437e31bd4c9301a073fac. (Last Accessed 16th April 2014).

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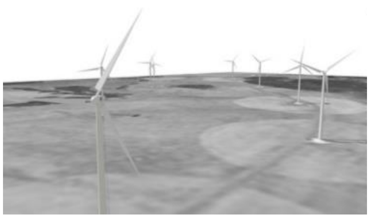
Wind turbines



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Trees (created in Unity using landscape tools)

Reference: (created by researcher, March 2012)

Building

Reference: Google Geo models. (2007). Chicago title and trust building. Retrieved from https://3dwarehouse.sketchup.com/model.html?id=901fc47a74a1c87b1b5dfde0d275ef54. (Last Accessed 9th March 2014).

Hills (created in Unity using landscape tools)

(created by researcher, March 2012)

Crane

Jeroen Hut (2009) Crane construction. Retreived from: https://3dwarehouse.sketchup.com/model.html?id=7e192ba9509a5488e4b68d3b17c43658. (Last Accessed 9th March 2014).

Monument

Damo (2009) Headingley war memorial. Retrieved from: https://3dwarehouse.sketchup.com/model.html?id=8d1538ac7cb7ba6df8b758b99bd30e5b. (Last Accessed 9th March 2014).

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Appendix H: Instructions given to participants for the virtual reality route learning task

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Before the task

"*Your task is to try and remember a route through some streets. You will need to use the joystick in front of you to walk around the route. Every time you get to a crossroads, you will see a yellow arrow and it will point in the direction you need to take. You will hear a noise when you walk through the arrow, just like in the practice task. This means that you are going the right way. You will walk around the route three times and on the fourth trial, the yellow arrows will disappear. Then it will be up to you to try and remember the route and walk in the right direction. I will let you know if you are going in the right direction after each turning and I will tell you if you go the wrong way. You will not be allowed to get lost! The streets all look very similar. The only thing that is different is the landmarks. These may help you to remember the route when the arrows disappear. We will point out the landmarks together as we go around. Do you have any questions? [Questions answered] You will see a start bar at the start of each lap and a finish bar at the end of each lap. When you are ready, please walk through the yellow start bar and this will start the task".*

Prompt before the test trial

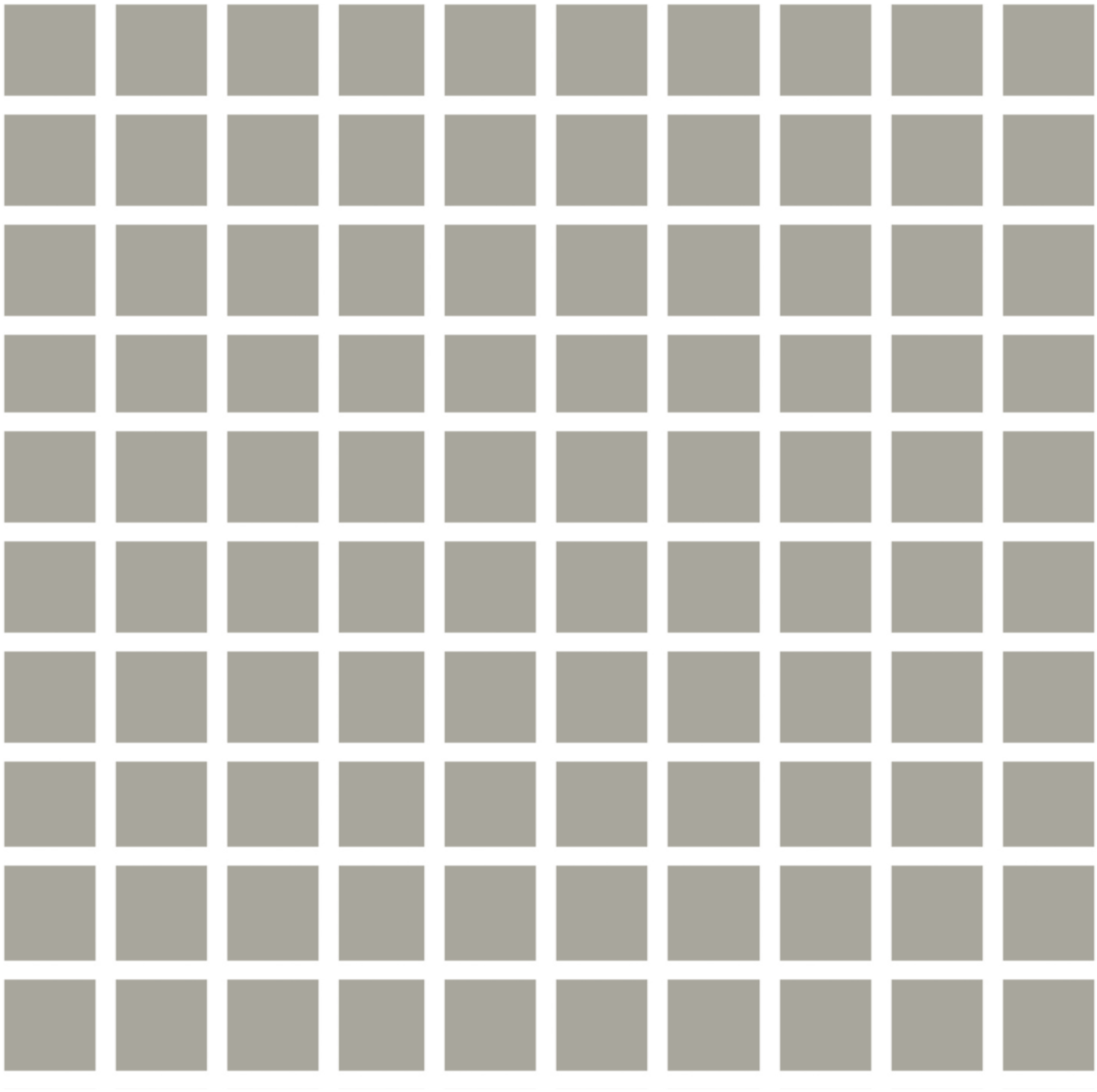
"Now this is your fourth lap and this time the arrows will not be there. It is your turn to try and remember the route. When you are ready, please walk through the yellow start bar and this will start the final lap".

Appendix I: Navigational strategies questionnaire

Please tick the most appropriate box that applies to you

	Not at all	A Little	A moderate amount	A lot	Almost completely
1. I tried to remember the sequence of left and right turns I took					
2. I had no idea of the way so I guessed					
3. I tried to develop a 'birds-eye' map in my head					
4. I tried to think in what direction I was going, in terms of North- South, East-West					
If so how did you know what direction was North- South, East-West:					
5. I tried to keep track of the general direction I came from and which way I was going					
6. I used buildings and other landmarks that I noticed along the way					
If so what were these:					
7. I used landmarks in the distance of my general direction to route myself					
8. I followed my instincts, without knowing how I did it					
9. I used the street signs					
10. I used a verbal description of the route as I went along and remembered that					
11. Please describe any other strategies you used to remember the route:					

Appendix J: Grid used by participants for map drawing



Appendix K: Studies from the literature review (Chapter 8)

Author	*Aim*	*Participants*	*Method*	*Results & Conclusions*	*Implications for rehabilitation*
External aids					
Liu et al., 2006	To describe design considerations and preferences when using a personal digital assistant to deliver directions wirelessly during wayfinding.	7 adults with cognitive problems of mixed aetiology (two TBI)	3 modes of delivering directions trialled within subjects (photo, audio & text; text & audio; text & photo) on 3 indoor routes. Prompts given when lost and confirmation given on completion of each individual direction.	Qualitative analysis, wide variation in ranking of modality preference. Need to adapt to individual's cognitive and physical ability. Audio directions alone seen as likely to be too fleeting.	Arrows to indicate direction on photos useful if kept simple. Need to use familiar vocabulary for text. Landmarks that were more visually distinct preferred. Care needed with timing directions if turns close together. Some concerns about being seen with equipment.
Sohlberg et al., 2007	Explore relative merit of 4 prompt modes on wrist worn electronic assistive device.	20 people with ABI and severe cognitive impairments.	Wayfinding tested along 4 equivalent 300m unfamiliar real life routes in town. Prompts were either: aerial map, point of view map, written text, or auditory prompt.	Performance better with auditory prompt than aerial map and point of view map and was also most preferred.	Need to consider whether strategy competes with task for cognitive resources.
Written aids					
Newbigging & Laskey, 1996	To teach independent bus travel to a man with memory	28yr old man, 8yrs post TBI, L frontal-parietal lesions.	5 walking routes and 3 bus routes taught. Each route first preceded by planning phase (tracing route on map with	All bus routes mastered within five trials. Direction sheets eventually reduced to	Purchasing bus pass reduced number of steps. Checking off turns ensured he attended to the route.

	problems and no previous experience of urban bus routes.		therapist). Walking routes - shadowed and prompted by therapist with map until mastered. Bus routes - sheet with task steps and road names, each turn ticked off by participant along the route.	laminated cards. Same technique used successfully later to teach other routes.	Laminated card used for emergency if lost and use simulated to aid learning. In vivo route learning recommended over simulated training.
Lemoncello et al., 2010a	To compare the effects of written landmark, cardinal and left/right street directions on navigational success at the beginning of a walking route	Two groups of participants: 18 adults with ABI and 18 controls matched for gender, age and education.	Participants followed written directions with landmark, cardinal or left/ right directions on a route following task at four locations and used prompts for orientation. Dependent measures included accuracy, directness, stated confidence and preference.	Participants with ABI produced more route following errors than controls when using cardinal and left/right directions. Both groups performed equally well with landmark-based directions. All participants preferred the landmark-based directions.	Landmark-based directions should incorporated in to rehabilitation
Cognitive strategies					
Rainville et al., 2005	To explore ability of man with: mild visual agnosia, prosopagnosia & topographical agnosia (inability to recognise famous and familiar landmarks) to orient himself in familiar and new environments.	71yr old man, progressive R temporal atrophy in fusiform gyrus and parahippocampus. R-L discrimination largely preserved & able to configure	2 outdoor tasks (finding way to location in familiar town via unfamiliar route; learn new route in unfamiliar town after one learning trial), one indoor pointing task & one task involving learning small scale spatial relationships blindfolded i.e. using only whole body information. Performance compared to controls.	In familiar town unable to recognise landmarks but could plan and execute route by relying on street names and names on buildings. In unfamiliar town performed at chance, could not recognise landmarks along path. However, acquired some spatial information of unfamiliar route as	Verbal strategy used to compensate for landmark recognition problem but use of street names was a less helpful strategy in unfamiliar environment. Controls relied heavily on landmarks to learn unfamiliar route.

		spatial relations between objects from different viewpoints. Five healthy males of similar age.		evinced by ability to perform path integration.	
Bouwmeester et al., 2014	To describe the rehabilitation process of a patient with severe topographical Disorientation over a 12 year period	35 year old man who had suffered a stroke, that resulted in severe damage to the medial occipito-temporal region bilaterally, predominantly on the right side	Longitudinal observation and route training on personally meaningful routes. Strategies included developing sets of directions, which contained smaller details of his chosen landmarks (without background or environmental information) and all with concise, written directions and some additional pictures of the features he was using.	Patient learned a set of new routes using these methods and could walk them without cues after 12 years. Able to identify new landmarks to use in the learning of new routes but relied on others to help him develop the written instructions. Patient gained in independence and in quality of life, but only within the limits of learned routes..	Extremely lengthy process but time needed to describe the precise nature of the topographic deficit and to design a tailor-made and structured intervention Routes can be taught and learned but need to be individualised to the goals of the patient. Routes taught using an egocentric frame of reference work well in this case.
Paterson & Zangwill, 1945	To describe a case of topographical disorientation and link findings to theory.	34 year old man with left neglect, amnesia, agnosia and apraxia due to penetrating head injury to R parietal region.	Longitudinal observation of patient's orientation in hospital & in familiar surroundings. Tested on ability to: draw plans of familiar surroundings, orientation on maps & verbal recall of local topography.	Observations suggested landmark recognition problems as well as difficulty recalling spatial relationships between familiar landmarks.	Patient naturally developed strategies to compensate e.g. focusing on signs on buildings colour or small individual features of landmarks.
Ciaramelli, 2008	To describe case of a man with	56yr old man, severe memory	Shown familiar map on computer screen & asked to	Participant tended to head towards familiar	Prefrontal ventromedial lesions may cause

	severe wayfinding problem and consider role of ventromedial prefrontal cortex in impaired wayfinding.	& executive problems due to subarachnoid haemorrhage. Bilateral lesions in ventromedial prefrontal and rostral anterior cingulate cortices.	describe route from start point to end goal. Standard condition (no screen prompt) vs three screen prompt conditions (appearing every 15s): name of destination; the words 'rehearse your destination'; or black rectangle (to control for possible alerting effect of prompts).	destinations rather than goal, either could not suppress interference or did not tag new spatial goal as priority over previous. Did better in reminding of destination and rehearse goal conditions.	difficulty keeping goal in working memory. Teaching man to rehearse goal along journey led to independent travel to work. Also generalised strategy to other situations.
Davis & Coltheart, 1999	To describe the rehabilitation of a case study with TD	46-year-old female patient, with isolated symptoms of TD	Development of mnemonics which aided verbal route memory to increase associations with meaningful material (names and locations of 14 streets in her town).	Significant improvement in recall of the taught items, which retained 2 months post-test. No evidence of spontaneous generalisation of mnemonic technique to other locations .	Authors suggest that "simple intervention strategies can be highly effective they are founded on a sound understanding of the patient's cognitive strengths and deficits, allowing the intervention to be precisely targeted" (p. 1).
Incoccia et al., 2009	To describe the rehabilitation of a case study who had never learned to navigate	20 year old, female. Suffered meningitis at six months old. Developed TD never developed navigational skills due to a cerebral malformation bilaterally	Patient trained to explore her surroundings, to orient herself and then to move in the environment using a cognitive/verbal strategy.	The patient was able navigate and orientate herself by using the trained strategies at the end of training and at one year follow-up. After one year, patient was This result was maintained at the one-year follow-up, at which time the patient was also able to reach locations	Patients who have never developed the ability to navigate, are able to learn and apply cognitive strategies to real world wayfinding with very tailored rehabilitation programmes.

		involving the retrorolandic regions.		she had never been to alone.	
Environmental adaption					
Antonakos, 2004	To describe everyday functioning and compensatory strategies in 3 people with topographical disorientation	Two people with stroke and one with TBI complaining of difficulty with independent travel.	Interviews and three tasks: find object hidden in room by researcher; imagine & describe what they saw on entering building; describe strategies used to get to places they travel to independently; discussion of use of maps and any other wayfinding strategies.	All had difficulty creating organised mental representations of objects in relation to each other in space. All had difficulty with maps.	Systematic scanning and memorising landmarks and landmark sequences useful strategies (but rely on memory ability). Organising home environment helped and cues to aid orientation e.g. leaving certain doors open.
Enhanced learning strategies					
Brooks & McNeil, 1999	To see whether routes learned in virtual environment generalise to real world in woman with dense anterograde amnesia. To see if learning is quicker in real world or virtual environment	53yr old woman with marked memory and executive problems due to subarachnoid haemorrhage. Tested on 10 simple routes around 30 room rehabilitation unit and not able to complete any.	Single case design across settings. Phase 1) trained on 2/10 routes in VR, 15 min session using backward chaining and then tested weekly on all 10 routes in real world. Phase 2) Two equivalent routes chosen one trained in real world, one in VR, both using backward chaining for 15 mins each. Tested weekly on all 10 routes in real world.	Phase 1) After 3 weeks could walk 2 routes trained in VR and one route not trained (a reversal of one of VR routes) no improvement on other 7. Phase 2) After 2 weeks had learned route trained in VR but not route trained in real world. 3 routes learned previously largely maintained and no improvement on untrained routes.	VR training generalised & suggests motor learning possible in amnesia without performing skill. Better learning on route trained in VR as: more training trials possible in 15mins, walking backwards in real world may compete for cognitive resources & many distractions in real world. Patient unaware she knew routes but told 'don't think, just have a go'.
Evans et al., 2000	To compared trial-and-error route learning with	Phase 1, 18 people with ABI and RBMT1	All aspects within subjects. Phase 1 - learn 10 step route around drawing of a room. 3	No difference between trial and error learning and any errorless	Errorless learning may only show advantage when retrieval takes place

	different types of errorless route learning methods (also studied name learning and learning to programme an electronic memory aid).	screening score ≤6. Phase 2, 16 people with ABI and mean RBMT screen score 3.5 (some also included in phase 1). Phase 3, 34 people with ABI and mean RBMT screen score 3.05 (*N* = 20 in stepping stone experiment).	conditions: trial and error, errorless using an instruction sheet, errorless using backward chaining. Phase 2, route around room reduced to 8 steps then trial and error vs forward chaining. Plus learning 9 step route over drawing of a stepping stone maze with trial and error vs errorless using a guided route. Phase 3 stepping stone route only, 13 steps chunked into 5,4,4 steps. Trial & error vs guided route.	learning method in any route learning or stepping stone experiment. Increasing active participation in learning and reducing confusion caused by appearing to learn route backwards (phase 1 to 2) made no difference. Chunking to facilitate use of working memory and reduce errors (phase 2 to 3) made no difference.	via implicit memory (implicating strengthening of neocortical associations rather than new episodic learning via hippocampus). Retrieval method for route and maze may therefore not confer errorless learning advantage. May have been insufficient learning trials to facilitate learning by strengthening neocortical connections.
Kessels et al., 2007	To test whether errorless learning is more effective than trial and error learning for route learning.	10 people, Korsakoff amnesia, mean: age 57yrs. RBMT1 route item standard score 1.1. Mean CVLT[2]standard score -5.8.	4 learning trials on unfamiliar route in hospital grounds then test trial. Errorless condition - photo shown at each decision point & told which way to go. Errorful – photo shown &asked to guess which way to go.	No difference between learning approaches.	Errorless learning may not be beneficial in route learning. Further evidence required based on well controlled studies of real life tasks.
Lloyd et al., 2009b	To compare errorless and errorful learning of novel routes in a non immersive virtual environment.	20 participants with acquired brain injury (8 TBI) and memory impairment.	Within subjects. 2 errorless learning trials in virtual town compared to 2 trial and error trials with corrective feedback. Each condition preceded by a demonstration of the route and followed by test trial.	Fewer errors made in errorless condition. 14/20 showed errorless advantage, those who did not, showed greater error correction on test trial of errorful condition	Errorless learning may be more effective for route learning especially in people who fail to learn explicitly. Further work required to test generalisation to real environment.

				than those who showed errorless benefit.	
Rose et al., 1999	To assess feasibility of using VR as a rehabilitation medium. To test whether passive vs active exploration of space facilitates learning.	48 people with vascular brain injury mean age 61 years. 48 healthy controls mean age 36 years.	Patients and controls randomly allocated to active exploration (using joystick) vs passive (watching replay of route of active participant) around 4 room bungalow whilst studying objects along the route & searching for toy car. Then tested on identifying shape of each room and location of door to next room in order to compile a layout, also tested on object recall and asked their impressions of VR.	Patients worse than controls on both tasks. Passive participants performed worse than active on bungalow layout (patients and controls). No difference between active and passive groups for patients on object recognition but active controls did better than passive (NB may have realised real aim of task).	VR was largely acceptable to all participants although some needed help to move out of tight corners. Active participation enhanced spatial learning in patients and controls. Suggested no effect for object recognition in patients as no procedural aspect to task to facilitate learning (i.e. not required to do anything with object).