AN INVESTIGATION INTO ROUTE LEARNING STRATEGIES FOR PEOPLE WITH
ACQUIRED BRAIN INJURY

By

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A thesis submitted to

The University of Birmingham

For the degree of

DOCTOR OF PHILOSOPHY

Department of Psychology

The University of Birmingham

November 2006

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Abstract

Individuals with acquired brain injury-related memory impairment learned routes around a complex virtual reality town under various conditions. Errorless learning, a technique used with considerable success in verbal learning tasks after brain injury (e.g. Baddeley & Wilson, 1994), resulted in significantly fewer route errors than trial-and-error (or 'errorful') learning, demonstrating the technique's potential for training practical daily living skills. The combining of explicit, naturalistic route learning strategies of cognitive map creation and landmark memorization with errorless learning did not, within the sample as a whole, further improve its efficacy. However, closer analysis of performance by participants with impaired verbal ability or deficits in executive function indicates that people with such cognitive profiles may derive particular benefit from these additional strategies. Applications and suggestions for further research are discussed.

Acknowledgements

My warmest thanks go to the following: My supervisor, Dr Theresa Powell, for providing excellent support and advice throughout the course of the PhD and reading through numerous drafts; Dr Gerry Riley, for great advice and suggestions; Jeanette Owen and the team at Headway North Staffordshire and Dr Louise Lorenc and the staff at Moor Green Brain Injury Rehabilitation Unit, South Birmingham PCT for all their help in the recruitment of participants; and Jennie Smith and Nathan Persaud for their help with data collection.

Acknowledgements are also due to the South Birmingham PCT; The University of Birmingham; and REMEDI, for providing the funding that enabled this research to go ahead, and to Reflections, ATARI, for providing the software used in the studies.

I also wish to express the deepest gratitude to everyone who took part in the studies, without whose generous participation the research would not have been possible.

Final thanks go to my family; especially my parents for raising me to believe I could achieve anything I set my mind to, without whom I might never have been crazy enough to attempt a PhD in the first place. I also want to thank my future in-laws for their support over the last three years. Last, but by no means least, all my thanks go to my fiancé Neil, who has been there through thick and thin to encourage and support me.

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CHAPTER ONE

GENERAL OVERVIEW

The major aim of this thesis was to investigate strategies for the rehabilitation of route-learning in people with acquired brain injury (ABI). Route learning is frequently impaired in ABI (Barrash, Damasio, Adolphs & Tranel, 2000), yet little research has been conducted into how best to compensate for route-learning deficits. The main aim of acquired brain injury rehabilitation is to reduce impairment and disability and improve quality of life (Cicerone et al, 2000; Wilson, 2000; 2002). This can be achieved through a range of interventions that have been classified as; compensation, substitution and restitution (Zangwill, 1947, in Wilson, 2000). It has been shown that memory does not respond well to a restitution approach (Cicerone et al., 2000; Wilson, 2000) and so the strategies most frequently used in memory rehabilitation are compensatory (Wilson, 2000). The distinction between substitution and compensation is subtle (Prigatano, 2005), and both are compensatory in a sense, but broadly speaking substitution involves employing assistive aids or other cognitive skills to entirely take over the impaired function(s), whereas compensation involves finding ways of using residual spared abilities (Wilson, 2000). Compensatory approaches can also enlist external aids such as organizers or diaries, or techniques that rely upon internal resources, such as mnemonics (Wilson, 2000).

In the context of route learning, compensatory strategies may be necessary in order to help people retain information about specific routes that are important for their every day lives

such as shopping, getting to work and socialising. The use of external aids, such as maps or satellite navigation systems, may be one way to compensate for route learning impairment, and many people within the general population use satellite navigation (Burnett, 2000) and traditional paper maps (Streff & Wallace, 1993). However, these aids are typically used for long or novel journeys, and it is arguable that people with ABI may feel reluctant to use them for short, frequent or simple routes, as they may be perceived to draw attention to the disability. Although this has not been directly addressed in route learning, studies using electronic diaries have found that some people with ABI are reluctant use the aids in everyday life due to embarrassment and fear of appearing lazy (Kapur, Glisky & Wilson, 2004). People with memory impairment may also be reluctant to use external memory aids because they fear they will impair spontaneous recovery of memory function, and they "don't want to rely on things like that" (Wilson & Watson, 1996, p.471). Furthermore, although user interfaces for satellite navigation are relatively straightforward, people with memory impairment may experience difficulties in learning to use new technology, evidenced by difficulty experienced by participants learning to use an electronic organizer, for example (Evans et al, 2000).

The aim of the present series of studies therefore, was to explore the use of 'internal' compensatory strategies and learning techniques to enable people to use residual skills for route learning, which rehabilitation professionals could then use to help people with memory problems to learn new routes so that they would eventually be able to recall them without reference to external aids. Wilson (2000) identifies three main techniques for capitalising on residual function that do not rely upon external aids; rehearsal of information, use of mnemonics, and application of errorless learning methods. The literature review on errorless

learning (Chapter 3) introduces this last technique in detail, as it is a particularly effective strategy for people with acquired brain injury (see Kessels & De Haan, 2003 for a meta-analysis), and is used throughout the patient studies reported in this thesis (chapters 7-9). Although this technique has met with mixed success in initial investigations of its applicability to spatial tasks (Brooks et al., 1999; Evans et al., 2000), it was considered a very important learning strategy to consider for use in the rehabilitation of route learning (for reasons discussed in Chapter 3). However, in addition to 'compensatory strategies,' such as errorless learning there are a number of strategies used in everyday life by people without ABI in order to help them find their way and remember routes (see chapters 2 & 5). An investigation into the usefulness of these 'naturalistic' (or spontaneously used) strategies in conjunction with the errorless compensatory approach is another main aim of the present studies. Because people without neurological impairment spontaneously recruit them on an everyday basis (Cornell et al, 2003), naturalistic strategies may, intuitively, be easy for people with ABI to use (even though they may possibly not spontaneously employ them, as is the case with mnemonics – Richardson, 1995). After Chapter 7 specifically examines whether errorless learning is effective in the field of route learning, therefore, Chapter 8 addresses the possibility of using errorless approaches in conjunction with naturalistic route learning techniques. Although, because of certain characteristics of errorless learning discussed in Chapter 3, learning via errorless methods may be specific to the route memorized, one would hope that incorporating easy to use naturalistic strategies with errorless learning may allow therapists to apply the methods to any route, or that the techniques may even be usable by the patient themselves independently, such as is the hope with strategies like problem solving training for executive problems and mnemonics (Evans, Emslie & Wilson, 1998).

Another important consideration in relation to the likely usefulness of a given strategy is the individual's pattern of cognitive deficits, and the particular constellation of preserved abilities that can be utilised (a tradition that extends back to Luria and underpins the rationale behind the use of certain strategies in specific patients today (e.g. Kreutzer & Wehman, 1999)). Chapter 9, therefore, examines the relationship between performance on a battery of selected neuropsychological tests and route-learning performance under various learning conditions.

A virtual reality town was chosen for the study of route learning in all of the studies reported in this thesis, as it was considered to provide both ecological validity and empirical control, along with having several practical benefits (see Chapter 4). There are, therefore, three diverse areas of literature that are pertinent to this thesis, and so three literature reviews are presented, the first of which introduces wayfinding and route learning; the second of which discusses errorless learning; and the third of which introduces the literature on virtual reality. Following the literature reviews, Chapter 5 reports a pilot study that assessed the validity of the virtual environment selected, by comparing neurologically healthy participants' route learning performance therein with their real-world route learning performance. Chapter 6 reports a second pilot study that investigated the relationships between route-learning strategy use, route learning performance (in the virtual town), wayfinding confidence and wayfinding experience. The aim of this study was, primarily, to identify two particularly effective naturalistic route-learning strategies for use by people with ABI. As mentioned above, Chapter 7 then reports a direct comparison of errorless and errorful route-learning learning techniques in a sample of participants with ABI, and Chapter 8 reports a study examining the

effect of using the naturalistic strategies (chosen by the pilot study in Chapter 6) in conjunction with errorless methods. Chapter 9 examines relationships between performance on a range of neuropsychological tests and route-learning performance under the different learning conditions. Finally, Chapter 10 gives a brief general discussion section summarising and integrating the findings from the five empirical studies reported.

CHAPTER TWO

WAYFINDING LITERATURE REVIEW

2.1 Introduction and Overview

The term 'wayfinding,' derived from the phrase 'finding your way,' has been given a variety of subtly differing definitions, with some defining it as 'the cognitive element of navigation' (e.g. Darken & Peterson, 2001, p1) and others arguing that it 'must encompass both movement and cognition' (Dalton, 2001, p26). In general the term is used to refer to all the processes involved in goal-directed movement through the environment from one place to another, a skill that is of great importance not only for humans but also for almost all animals that need to move around in a logical manner. Impressive wayfinding abilities in insects such as bees and ants, various species of bird, and mammals such as dogs and rats (e.g. Collett & Collett, 2000; Hunt & Waller, 1999), suggest that at least some of the cognitive mechanisms of wayfinding are phylogenically old. In human wayfinding research, a range of conscious or explicit strategies, many based around language, are typically also reported (e.g. Kato & Takeuchi, 2003), so it appears that wayfinding in humans is sub-served by a broad range of cognitive mechanisms.

Wayfinding research has applications in the field of Geography (e.g. Golledge, Dougherty & Bell, 1995), urban planning and design (Fewings, 2001), the military (e.g. Darken & Peterson, 2001), and, of course, Psychology. Psychologists are interested in the cognitive aspects of

wayfinding, such as the way in which we perceive and interact with the world, and also in cases in which there is impairment in wayfinding ability, for example in people with learning difficulties (e.g. Cromby, Standen, Newman & Tasker, 1996), brain injuries or stroke (e.g. Brooks et al., 1999, Rose et al., 1999), or degenerative diseases like Alzheimer's dementia (e.g. Uc et al., 2004a;b).

The studies reported in this thesis are concerned specifically with the specific aspect of wayfinding known as route learning. The term 'route learning' is often used alongside (or interchangeably with) the term 'wayfinding.' In fact, the dictionary definition of a route is 'a particular *way* or direction between places'[1] {my italics}. Yet while there is much overlap between the two terms, they are not entirely synonymous. 'Route learning' generally describes the learning and memorising of a pre-specified, particular route or path, and while this is clearly a type of wayfinding, the inverse is not necessarily always so. The goal of wayfinding can sometimes be to remain oriented in an exploratory trip, for example, rather than to trace a set route from point A to B. Even when the goal of wayfinding *is* to arrive at a set destination, it may be successfully executed *without* the memorising of a route, for example by heading directly for a distant landmark, or by using a map or compass. This chapter covers literature on both wayfinding in general and route learning in particular, as many general wayfinding studies have great relevance to route learning.

The decision to study route-learning rather than the broader task of wayfinding was based, primarily, upon general observations from previous research into brain injury rehabilitation.

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[1] Online Cambridge Advanced Learner's Dictionary; http://dictionary.cambridge.org/cald/

Successful generalised remediation of memory after the initial period of recovery post- brain injury is very rare, and there is a strong consensus that techniques aimed at re-training participants in specific, constrained tasks are more likely to be effective (see Wilson, 2000, for a discussion). The technique known as errorless learning (introduced fully in the following chapter), whilst it has been successfully used to improve retention rates for specific pieces of information in people with ABI (e.g. Baddeley & Wilson, 1994) typically results in very poor generalization to untrained material. Training people with memory impairments to remember specific routes, therefore, was deemed a more realistic and attainable goal than attempting to bring about a general improvement in wayfinding ability. The overall aim is to provide practical solutions for wayfinding impairments, but the theoretical implications are also, of course, of great interest to the study.

This chapter first describes the main strategies that can be employed when wayfinding. There follows a review of the various environments in which wayfinding has been studied and the outcome measures that have been employed, and their associated advantages and disadvantages. Individual differences in approaches to, and performance in, wayfinding tasks are then addressed. An introduction to wayfinding in ABI is then given.

2.2 *Wayfinding Strategies*

The distinction has been made in the literature between two major types of wayfinding strategy; 'route' and 'survey' based (e.g. Lawton, 1994; Prestopnik & Roskos-Ewoldsen, 2000), and some researchers also specify a third category of 'landmark' based strategies (e.g. Pazzaglia & De Beni, 2001). Route-based strategies typically involve taking an egocentric, or

'worm's-eye' perspective of the environment and memorizing of specific routes between locations. Survey-based strategies (also known as 'configurational' 'orientation' and 'Euclidean' strategies) involve an exocentric perspective, and typically involve the creation of a mental 'bird's-eye' map of the environment (Kirasic, Allen & Siegel, 1984; Lawton, 1994). Landmark-based strategies involve basic use memorization of isolated landmark-turn combinations (Pazzaglia & De Beni, 2001). These categorizations can be somewhat misleading, as landmarks are typically used in all three types of wayfinding, and survey-based techniques can be as effective as route based techniques for route learning (e.g. Aginsky, Harris, Rensink & Beusmans, 1997). Because of this, and as the present series of studies is concerned with the identification of specific everyday strategies that are useful for route learning, these categories are used mainly only when referring to others' findings.

At least seven specific, everyday route-learning strategies have been identified in the literature. Three of these, introduced in a checklist used in a route learning study by Kato and Takeuchi (2003), are: use of a cardinal reference system (i.e. the compass points North, South, East and West); turn-sequence memorization (i.e. the memorization of a string of commands such as 'first left... second right... straight ahead...'); and use of landmarks (i.e. the use of buildings or other distinctive features of the environment as reference points). Landmark use can be divided into the use of landmarks along one's route ('local' or 'proximal' landmarks) as aids to memory; and the use of landmarks visible from a distance ('distal' or 'global' landmarks) as memory and / or orienting aids (Cornell, Soronsen & Mio, 2003; Jacobs, Laurance & Thomas, 1997).

Another major wayfinding strategy is a technique known as 'dead reckoning,' which has been defined as a process of 'continuous integration of translational and angular components,' which 'allows for estimation of direction and distance from a point of origin' (Cutmore, Hine, Maberly, Langford & Hagwood, 2000, p.224). The term 'path integration,' is sometimes used synonymously with dead reckoning (Worsley et al., 2001).

A strategy that has received little attention in the literature is known as the 'look-back' strategy (Heth, Cornell & Flood, 2002), which involves turning around periodically whilst following a new route in order to familiarize oneself with the return perspective.

A final important wayfinding technique, seen by some as the ultimate and most developed wayfinding strategy (e.g. Siegel & White, 1975), is the creation of a mental map of the environment, or 'cognitive mapping', which may facilitate, as would a real map, calculation of short-cuts; direct distances between points; and new routes between locations (Prestopnik & Roskos-Ewoldsen, 2000).

To summarise, the major route-learning strategies studied in the wayfinding literature are the use of cardinal reference points; the memorization of turn sequences; the use of proximal landmarks; the use of distal landmarks; dead-reckoning; the use of a 'look-back' technique; and cognitive mapping. The relative effectiveness of each of these strategies is addressed in Chapter 6, which describes findings from the literature and goes on to empirically assess the relationship between each of these strategies and route-learning performance.

2.3 Assessing wayfinding: Environments and outcome measures.

A large range of environments, tasks, and outcome measures have been employed in the study of wayfinding, sometimes to assess it as a unitary construct, and other times to examine the component skills potentially involved. Environments used vary in terms of their realism or ecological validity (from simple mazes to real city centres), their scale (from single rooms to whole regions), their complexity (from sparse rooms to busy towns) and their location (indoor or outdoor, urban or rural areas). In addition, certain wayfinding assessments do not require a particular environment per se. Generally the trade off between complex, real world environments and simpler laboratory or maze-based tests, is between experimental control and ecological validity, although some environments can offer a better compromise between these than others (Loomis, Blascovich & Beall, 1999).

2.3.1 Self-report

Self-report measures have been used to assess participants' self-perceived wayfinding ability or skill (e.g. Cornell et al., 2003), their experience (e.g. Lawton & Kallai, 2002), their confidence (e.g. Kato &Takeuchi, 2003), or their favoured techniques (e.g. Pazzaglia & De Beni 2001). The advantages of self-report measures are their ease of administration, and the fact that questionnaires can cover a wide range of topics, asking participants to report on behaviours that may be difficult or impossible to assess empirically. Self-reports are particularly invaluable for gathering practical details about a person's wayfinding behaviour, such as the amount of wayfinding experience they have and the frequency with which they encounter various environments (e.g. Lawton, 1994). Subjective variables such as wayfinding confidence are also difficult to assess via any means but self-report.

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In assessing participants' strategy use, self-report is a particularly parsimonious method of gathering information. The alternative to self-report is to deduce, from scores on specific tests, whether a person seems likely to have employed a given strategy. For example, if a person is able to create an accurate sketch map of an area, the experimenter may deduce that they use the strategy of cognitive map creation (Billinghurst & Weghorst, 1995). Self-report, however, allows for evaluation not just of how effectively a person uses a strategy, but also of whether and to what extent they *attempted* to use the strategy, regardless of whether they were proficient. It can also provide information about the extent to which a person favors certain strategies over others.

Disadvantages of self-report measures of strategy use include the fact that route learning is at least partially procedural (Allen & Willenborg, 1998, Garden, Cornoldi & Logie, 2002), which could suggest that the processes involved are not entirely accessible to consciousness. However, the validity of self-report measures is supported by empirical evidence. For example, the theoretical division between 'route' and 'survey' based wayfinding described above, often based upon factor analysis of self-report questionnaire data (e.g. Lawton, 1994; Prestopnik and Roskos-Ewoldsen, 2000), is borne out in the analysis of sketch-maps produced in actual wayfinding tasks (Aginsky et al., 1997).

Because of their aforementioned advantages, self-report measures were employed in the pilot study described in Chapter 6, which assessed relationships between strategies employed in a route learning task and performance on that task, along with the correlations between strategy

use and the frequency with which participants experience novel situations necessitating wayfinding, and the differences between males and females in strategy preference.

Wayfinding *ability* is somewhat more problematic to assess via self-report than confidence or strategy use because it may (as with all self-report measures of ability) be prone to distortion due to lack of insight or to response biases. Nevertheless, several studies have found relationships between participants' self reported ability and objective measures of their performance. Billinghurst and Weghorst (1995) found self-reported feelings of orientation and knowledge of positioning of things within virtual environments correlated with accuracy of sketch-maps produced, although the use of relatively simplistic arrays of 'landmarks' may have meant that participants were able to predict their performance unusually accurately. Support for the validity of self report measures of ability using real-world settings, however, comes from both Kato and Takeuchi (2003) and Cornell et al. (2003), who found that participants who rated themselves as a having a good 'sense of direction' outperformed those who rated their sense of direction as 'poor' on a route-recall task (Kato & Takeuchi, 2003) and a task involving pointing out the directions to landmarks (Cornell et al., 2003). Self-report did not predict ability to produce a sketch-map of a route or accuracy in pointing out the direction of a route's start-point (Kato & Takeuchi, 2003), however, this may be because people rate their sense of direction according to their ability to perform tasks required in everyday life (i.e. following a route), but do not take into account their ability to perform more abstract or scarcely used skills such as sketch-mapping.

In light of the evidence supporting the validity of self-reported sense of direction, all of the studies conducted with patients with ABI (chapters 7 through 9) asked participants to rate their sense of current sense of direction and estimate their sense of direction prior to their brain injury. It was hoped that this would provide some measure of the performance decrement in wayfinding ability participants' had experienced following their injury.

A similar to but distinct construct from sense of direction that has been measured by self-report is wayfinding confidence (e.g. Cornell et al., 2003), or, seen from another angle, wayfinding anxiety (Lawton, 1994; Lawton & Kallai, 2002). Individual difference variables of age and gender influence amount of wayfinding anxiety, with males tending to be more confident (Prestopnik and Roskos-Ewoldsen, 2000) and less anxious (Lawton & Kallai, 2002) than females, and a positive correlation between age and self-reported wayfinding anxiety emerging (Lawton & Kallai, 2002). Links between anxiety and approaches to wayfinding have also been demonstrated, with those who use an 'orientation' strategy being less anxious than those who use route based techniques (Lawton, 1994; Lawton & Kallai, 2002). Self-ratings of confidence could be argued to differ from self-ratings of sense of direction in that they encompass more than simply an estimate of one's ability, inviting participants to express their feelings about various wayfinding situations. In the present series of studies measures of wayfinding confidence are included to provide a subjective measure of how comfortable people feel in various scenarios where they have to find their way.

2.3.2 Pencil-and-paper tests

Various pencil-and-paper tests have been used to examine cognitive skills purportedly related to wayfinding. The Money Road Map Test (Money, Alexander & Walker, 1965), for example, asks participants determine whether each turn on a 'route' marked out on a grid of generic 'streets' is a left or a right, assessing the mental rotation skills involved in following a route on a map. Attempts have also been made to predict wayfinding performance from scores on neuropsychological tests of more general cognitive abilities, with mixed results (e.g. Moffat, Zonderman & Resnick, 2001; Nadlone and Stringer, 2001).

While pencil and paper tests of wayfinding tend to lack ecological validity (e.g. Nadolne & Stringer, 2001), they are reliable and highly controlled measures, and usually easy to administer. Because there has been some success in the use of standardized neuropsychometric tests in predicting wayfinding performance (e.g. Moffat et al, 2001), therefore, experiment 5 assessed relationships between route learning performance of people with ABI and scores on a selected battery of psychometric tests battery. Tests were selected based upon findings from studies that have had some success in predicting wayfinding performance, and are described in detail in Chapter 9.

2.3.3 Laboratory-based tasks

There are a few outcome measures that can be used to assess wayfinding somewhat more practically than questionnaires or pencil-and-paper tasks allow and can be administered in a controlled, laboratory setting. Distance and direction estimation tasks, in which participants estimate the positions of various landmarks, are usually conducted 'in the field' (e.g. Kirasic

et al., 1984, Cornell et al., 2003, Kato & Takeuchi, 2003), but can also be carried out in the laboratory, by asking participants to imagine that they are at a given location facing in a set direction (e.g. Cornell et al., 2003). Both types of pointing task attempt to measure configurational knowledge; one's understanding of the direct positioning of items in the environment in relation to one another, from a survey perspective. As the present series of studies was interested specifically in route learning, rather than in participants' development of configurational knowledge of an environment, distance and direction estimation tasks were not employed.

2.3.4 Mazes

Moving on to 'real,' three-dimensional test environments, one of the most basic, and arguably least ecologically valid, is the maze; usually a network of homogeneous lengths of enclosed passageway, with numerous junctions. In wayfinding research, mazes also sometimes contain simple markers, such as coloured objects or symbols, to function as landmarks (e.g. Golledge et al. 1995), although these are arguably quite different from everyday landmarks like buildings or statues. Although they are, in their simplicity, dissimilar to typical real world wayfinding environments, many of their strengths lie in this simplicity. Because the sensory input within a maze is limited, it can, theoretically, isolate individual components of wayfinding (e.g. Mallot, Steck & Loomis, 2002). Again, however, because the present series of experiments sought to investigate the practical utility of techniques for learning typical outdoor routes, mazes were not employed.

2.3.5 Real-world environments

Clearly, real world environments are the most ecologically valid setting for wayfinding studies. Indoor environments used in wayfinding research range in size from houses (e.g. O'Laughlin & Brubaker, 1998), and offices (Beaumont, Gray, Moore & Robinson, 1984), to hospitals (eg Brooks et al., 1999) and airport terminals (e.g. Fewings, 2001). Outdoor environments range from urban areas (e.g. Uc et al., 2004a;b) to University campuses (e.g. Kirasic et al., 1984; Cornell et al., 2003) and open (countryside) terrain (Darken & Banker, 1998).

In indoor settings it is easier to control for participants' familiarity with the test environment, and variability of cues, but there is also the possibility of ceiling effects, with the scale usually being smaller than that of outdoor environments, and cues such as floor and room numbers providing clear guidance. Because there are also often people located within large buildings that know its layout and can be approached for assistance, the practical utility of researching wayfinding strategies for indoor environments is arguably less than that of researching outdoor wayfinding.

There are a number of methodological difficulties associated with studying wayfinding outdoors. Often, cues to outdoor wayfinding are temporary or variable in nature, such as parked vehicles and temporary signage, sounds and even vegetation, when studies run over extended time periods, (Vinson, 1999). Prior familiarity of a participant with the test area can also be a confounding factor; Kirasic et al. (1984), for example, were unable to determine whether gender differences in an outdoor wayfinding task were simply attributable to

differential familiarity of males and females with certain locations on campus. Assessing participants in a completely novel large-scale environment bypasses this difficulty, but increases demands upon time and resources, and may limit the availability of willing participants. Safety issues are another disadvantage of real world studies, where numerous dangers and distractions exist, such as traffic, other pedestrians, and tripping and falling hazards. Although such risks are typical day-to-day hazards, they are particularly worrying in studies with individuals who may be in some sense vulnerable or impaired, as in the present series of studies with participants with ABI. Virtual reality (VR), discussed below, may offer a solution to the difficulties associated with assessing real world outdoor wayfinding.

As the outcome measures used to assess wayfinding in real and virtual environments are largely identical, these are discussed shortly, after the introduction of VR environments in wayfinding research.

2.3.6 Virtual Reality environments

Wayfinding research has recently begun to make increasing use of VR software (see Chapters 4 & 5). Interactive simulations of relatively realistic, three-dimensional environments may offer one of the best compromises between experimental control and ecological validity (e.g. Loomis et al., 1999). This is one of the main reason for the use of virtual reality in the present series of studies.

A specific deficit in VR wayfinding is the lack of proprioceptive, kinaesthetic or vestibular feedback available, all of which may be used in wayfinding (Berthoz & Viaud-Delmon, 1999,

p708), and cannot be provided by the vast majority of VR packages. However, there is evidence that visual input, which virtual simulations do provide very convincingly, over-rides sensorimotor input (Aginsky et al., 1997). Furthermore, despite lack of physical feedback in typical VR studies, there is a great deal of evidence for the equivalence of real and VR wayfinding (see Chapters 4 & 5)

2.4 Outcome measures in real world and virtual reality wayfinding studies

Outcome measures used in real world and VR studies can be divided into two main categories; measures of route knowledge and measures of configurational knowledge, although some studies also assess memory for scenes or landmarks encountered within an environment (which may fall into either category).

Participants' recall of landmarks is typically assessed with recognition tests in which participants identify images of landmarks they have seen from amongst similar distracters (e.g. Maguire et al., 2003). While this test is not essentially assessing practical wayfinding ability, there is certainly an intuitive relationship between ability to recall (or recognize) landmarks and wayfinding behaviour. Landmarks recognition tests have been used in both VR (Maguire et al., 2003) and real world (Cornell et al., 2003) wayfinding studies, but were not employed in the present series of studies.

The most widely-used measures of configurational knowledge are: assessing the accuracy of participants' estimates of the distance and direction between various locations within an environment (as introduced in the section on laboratory based assessment, above) and asking

participants to calculate short-cuts within an environment (e.g. Cornell et al., 2003); and asking participants to produce a map of the layout of a route or environment ('sketch mapping') (e.g. Billinghurst & Weghorst, 1995). All of these measures can typically be implemented in both real and virtual environments, but are not used in the present series of studies, which aimed to assess learning of specific routes, rather than acquisition of configurational knowledge.

Ability to take a detour or 'short-cut' is a particularly ecologically valid skill to assess, with clear real-life applications, but as it would not necessarily be expected to effect straightforward route learning ability, it is not used as an outcome measure in the present series of studies.

Researchers have examined the maps people produce of an environment, in the belief that their configurational accuracy reflects the extent of survey knowledge held (Aginsky et al., 1997), and sketch-mapping has been used in real (e.g. Stanton et al., 2000,) and virtual (Billinghurst & Weghorst, 1995) environments. However, the *scoring* of sketch-maps is notoriously difficult, not only because 'a good map is always evidence of a good representation, but a bad map may simply be a sign of a poor artist' (Hunt & Waller, 1999, p 8), but also because there are no concrete criteria by which to score sketch-maps. For example, scoring methods biased towards rewarding configurational accuracy would produce different results than those rewarding correctly depicted sequences of turns. Nevertheless, there have been some successes with sketch-maps. Aginsky et al. (1997) categorized maps as falling within various 'types', and found that the proportions of each type of map within their

sample matched the reported proportions of certain types of wayfinder. Maguire et al. (2003) employed a computer programme which allowed participants to compile a map by dragging and dropping pre-drawn elements onto a grid, thus avoiding the confound of drawing ability. Sketch-mapping was not used as an outcome measure on the present series of studies, again because the skill of interest was route learning, which does not necessarily correspond to configurational knowledge (e.g. Siegel & White, 1975).

The most obvious measure of route-knowledge is to ask participants to retrace a route they have learned, and record the number of incorrect turns taken, the time taken, or the length of the path taken, although it can also be assessed by asking people to estimate the distance, on foot (rather than direct or 'as the crow flies') from one point to another. The ease of scoring route reproduction varies with the amount of feedback given during the task. When people are corrected as soon as they begin to take a wrong turn, the number of corrections (i.e. number of wrong turns) is the obvious outcome measure. If people are asked to walk a route they have just learned, and are given no feedback when a wrong turn is taken, participants may produce drastically differing paths, and number of wrong turns may not be an appropriate measure, because participants are exposed to a different number of opportunities to make errors, with those who take a wrong turn early-on being faced with many more choice points at which further wrong turns may be made than those who stay on course longer before making an error. In scenarios like this, one outcome measure that has been employed is 'spread of wandering' (Heth, Cornell & Flood, 2002), whereby the course a participant takes is plotted on a map and a geometric technique is used to calculate the range of the area within which they have wandered. This method also has its flaws, for example a person who takes one

wrong turn into a long, straight road pointing directly away from the correct path may seem to wander much further away than someone who takes multiple wrong turns but stays in the vicinity of the correct path, though it is not clear that the latter person knows the route any better than the former.

For assessing route recall in the present series of studies, number of incorrect turns was considered the most practical outcome measure. Because a virtual environment taken from commercial software was used, the option of recording path length was not available. The use of feedback at each turn, allowing for straightforward measure of number of incorrect turns out of a maximum of the total number of junctions on the route, was seen as the most appropriate option for several reasons. Because some participants were expected to be particularly impaired in their route recall, allowing participants to become lost and measuring number of incorrect turns taken or spread of wandering would have potentially been very demoralizing. Furthermore, because the amount of wandering possible would vary depending upon the point at which a wrong turn was taken, or number of uncorrected turns could increase exponentially if a participant failed to return to the route, these measures were seen as prone to somewhat random variation.

2.5 Individual differences in wayfinding

There are notable individual differences in wayfinding ability. As Kato and Takeuchi observe, while some people easily learn routes in just one trial, others need to expend much more time and effort (Kato & Takeuchi, 2003). Individual differences in wayfinding can be roughly grouped into those related to the 'hardware' (i.e. the cognitive profile, the gender, the age) of

the wayfinder, versus those involving the 'software' (i.e. the strategies) of the wayfinder, and these factors are likely to interact. It is believed, for example, that the male superiority in mental rotation (e.g. Richardson, 1994), is one of the reasons they are more likely to create a mental map of an environment, as efficient map use involves mental rotation (e.g. Darken & Cevik, 1999).

This section reviews the main individual differences in wayfinding, focusing particularly on gender, age, and experience. Strategy use is a particularly important factor to consider when studying wayfinding, and individual differences in strategy use are mentioned throughout this section, but a fuller account of the strategies employed in wayfinding is provided in empirical chapter two, in which relationships between route learning performance and wayfinding are assessed.

2.5.1 Gender

Gender differences are a contentious issue in wayfinding research, and have been demonstrated in performance, confidence, and also in the strategies employed during wayfinding, yet there are also a large number of studies that fail to find any differences at all (see Collucia & Louse (2004) or Tlauka, Brolese, Pomeroy, & Hobbs (2005) for a review).

In terms of performance, a recent meta-analysis revealed that around 60% of studies report a male superiority and 40% report no gender differences, whilst no studies actually report a female advantage (Collucia & Louse, 2004). A likely reason for this inconsistency is the multitude of factors potentially interacting to determine performance on any given task, from

the environment (e.g. Lawton & Kallai, 2002) to the type of wayfinding cues available (Saucier et al., 2002), to the actual means of assessment (e.g. Cornell et al., 2003). Collucia and Louse (2004) found that females tend to equal males on many accuracy measures, but show longer reaction times, and consistent with this Cornell et al. (2003) found a male advantage not in length of short-cuts taken but in time taken to calculate them. Other studies *have* revealed male superiority in accuracy measures across a range of test environments, however, such as in indoor route learning (Pazzaglia & De Beni, 2001), direction estimation tasks (Prestopnik & Roskos-Ewoldsen, 2000), and VR maze tasks (Moffat, Hampson & Hatzipantelis, 1998; Moffat et al, 2001).

Several studies have found females' wayfinding confidence levels to be lower than those of males (e.g. Lawton & Kallai, 2002, Prestopnik & Roskos-Ewoldsen, 2000), and this cannot be attributed simply to differing levels of trait anxiety (Lawton & Kallai, 2002). This gender difference may reflect differences in ability, as Devlin and Bernstein (1995), for example, found that males' were more confident than females and also performed better than them in a campus route learning-task. However, O'Laughlin, & Brubaker (1998) found lower confidence ratings from females despite a lack of gender difference in objective task performance, suggesting that females' lower confidence is not always an accurate reflection of their actual ability.

Gender differences in strategy use have mainly been identified via questionnaire measures (e.g. Prestopnik & Roskos-Ewoldsen, 2000). Males report more frequent use of cardinal directions than females (Lawton, 1994; McFadden, Elias & Saucier, 2003) and a preference

for distance and direction information while navigating (Tlauka et al., 2005), and they are more likely to report employing exocentric 'orientation' or 'survey' strategies (Lawton & Kallai, 2002). Females appear to prefer strategies relying upon the layout of landmarks and the sequential routes between them (Lawton, 1994, Lawton & Kallai, 2002), and may have a preference for verbal strategies: They express a greater desire for road-signs than males (Burns, 1998), solve mazes more effectively under conditions which allow routes through them to be learned as a verbal sequence (Bever, 1992, in Cutmore et al., 2000), and report memorizing of lefts and rights when learning routes more than males do (Kato & Takeuchi 2003, Lawton, 1994). One study also found that females' verbal memory correlated with their route learning performance, whilst males' did not (Garden et al., 2002).

Theories about the aetiology of gender differences include biological explanations, based around the influence of hormones on wayfinding performance (e.g. Moffat & Hampson (1996) in Coluccia & Louse, 2004) evolutionary perspectives (e.g. Silverman & Eals, 1992, in Collucia & Louse, 2004) centering around the wayfinding requirements of the early male in his role as hunter-gatherer, and more environmental explanations, suggesting that gender differences are attributable to factors like parents allowing a greater range of independent exploration outside the home for males than for females (Lawton & Kallai, 2002).

In light of the clear possibility of gender differences in wayfinding techniques and / or performance, gender effects are assessed in the pilot study carried out with neurologically healthy participants, reported in Chapter 6.

2.5.2 Wayfinding Experience

Experience is another important variable in wayfinding research, and it is conceivable that the extent of an individual's experience of wayfinding could influence their confidence, ability and / or strategy use (e.g. Lawton, 1994, Prestopnik and Roskos-Ewoldsen, 2000). It is also possible that wayfinding ability actually influences experience, in that people with good wayfinding skills may be more likely to enter into situations requiring navigation.

Experience has been assessed in terms of familiarity with the actual test environment (Kirasic et al., 1984), and in terms of childhood wayfinding experience (Lawton & Kallai, 2002). Kirasic et al. (1984) found that students who had been at a university longer were more systematic than newer residents in their estimations of distance and direction of various points within the campus. Lawton and Kallai (2002) found that (retrospectively reported) amount of childhood wayfinding experience was negatively correlated with wayfinding anxiety. They also found a small correlation between this experience and scores on the orientation (survey) strategy factor of their questionnaire.

Relationships between experience and ability could suggest an environmental origin for the aforementioned sex differences (and other individual differences), although it is also conceivable that more naturally able wayfinders are most likely to frequently undertake new journeys and thereby gain more experience of wayfinding. Because experience does appear to have some relationship with wayfinding performance and confidence and with approaches to wayfinding, the present series of studies included measures of participants' wayfinding experience. Whereas previous studies have attempted to assess how experience during

development influences wayfinding, however, the present studies focused more narrowly on participants' typical experience in the present. This was because the aim was not to systematically investigate how experience might take effect in the long-term, but merely to determine whether people who tended to take more trips to new places were more likely to be better route-finders. While causality would not be attributable from such a correlational analysis, an exploratory assessment was considered of interest, if only to highlight possible relationships for further study.

2.5.3 Age

There is some evidence for an age-related decline in wayfinding ability (e.g. Moffat et al., 2001; Wilkniss et al., 1997), and wayfinding anxiety has also been found to correlate with age (Lawton & Kallai, 2002). Imaging data taken during a VR wayfinding task also identified different patterns of cortical activity in older and younger adults (Moffat, Elkins & Resnick, 2006), suggesting age differences in performance may be attributable to older and younger participants recruiting different cognitive processes in the execution of wayfinding tasks.

Because studies of age effects upon wayfinding have tended to use polarized age groups, often with a mean difference in age of over 40 years (e.g. Moffat et al., 2006; Wilkniss et al., 1997), it is not possible to determine whether the age effect is a consequence of gradual age-related decline in memory in general, or whether differences in the way older and younger generations learned to navigate may be responsible for the effect.

Age effects upon wayfinding were not of particular interest to the present series of studies, and because the studies of route learning techniques in participants with ABI both used a within-participants design, there was no risk of age acting as a confounding variable.

2.6 Wayfinding in acquired brain injury

There are multiple cognitive mechanisms potentially involved in wayfinding that can be impaired in ABI, from the cognitive skills involved in processing the environment (such as mental rotation, cognitive map formation and landmark selection), to those involved in recalling it (visuo-spatial memory and verbal memory), there are many ways in which ABI can impact upon wayfinding ability (Aguirre & D'Esposito, 1999). Recall of retrograde and anterograde information may also be differentially affected by brain injury (Barrash et al., 2000). Specific deficits have been observed in ability to recognise landmarks or scenes – termed topographical agnosia (Clarke, Assal, & de Tribolet, 1993); in the ability to recall landmarks or scenes – termed topographical amnesia (Turriziani et al., 2003), and in the ability to judge spatial relations between objects – termed topographical disorientation (Aguirre & D'Esposito, 1999). Cases in which these deficits are experienced in pure form are relatively rare, however, and findings from patients with these impairments are usually reported as single case studies (Barrash et al., 2000); more often, wayfinding difficulties are likely to be part of a pattern of generalised memory deficits (e.g. Hartley, King & Burgess, 2003). The studies reported in this thesis do not assess the aetiology of participants' wayfinding difficulties, as they aim to identify route-learning techniques that can be applied successfully across patients with a broad range of memory impairments. However, neuropsychological assessments are carried out in Chapter 9, in an attempt to determine

whether they can predict participants' route learning impairment and their performance under various learning conditions (see Chapter 9 for more detail).

As most studies of wayfinding impairment in ABI have focused in single cases or small numbers of participants (Barrash et al., 2000), there is little information available as to the overall incidence of such impairments, although several studies demonstrate that, on average, samples of participants with ABI are impaired relative to neurologically healthy controls in ability to remember directions (Uc et al., 2004a), navigate in a virtual maze (Skelton et al., 2000), and navigate around a virtual town (Spiers et al., 2001).

Barrash et al. (2000), provide a breakdown of the percentages of participants with various lesion locations who reported experiencing wayfinding deficits in everyday life. Of a sample of 127 participants with ABI resulting from lesions to a broad range of brain regions, 31 % experienced wayfinding impairment. Of participants whose lesion involved medial temporal cortex, posterior parahippocampal cortex, the right hippocampus, or the right inferotemporal region, however 86% experienced wayfinding impairment. In other words, when lesion location is unspecified, in a heterogeneous group of people with ABI, almost one-third report wayfinding impairment, and for groups with injury to particular cortical areas the incidence rate rises to around six people in every seven. Clearly deficits in wayfinding ability are commonplace following ABI, justifying the present series of studies into learning strategies to improve route recall in people with ABI. As mentioned earlier, route recall was chosen for study rather than wayfinding ability in general in light of evidence that rehabilitation of

specific tasks is more likely to be effective than interventions designed to promote generalised improvement in cognitive ability (e.g. Wilson, 2000).

2.7 Summary

Wayfinding, and route learning, involve numerous cognitive processes, and as such can be adversely affected by ABI on a range of levels. Most samples of participants with ABI perform, on average, worse than neurologically unimpaired controls on tests of wayfinding ability, and at least a third of people with ABI report wayfinding difficulties in everyday life. The present series of studies focuses on the specific practical wayfinding task of route learning, and compares the effectiveness of a range of techniques for improving performance in people with ABI. A VR environment is used, in order to capitalise on the good trade-off it provides between ecological validity and experimental control, and route-learning performance is assessed via a simple measure of wrong turns made during route recall.

CHAPTER THREE

ERRORLSS LEARNING LITERATURE REVIEW

3.1 Overview

Errorless learning is the name given to learning episodes in which effort is made to prevent errors from occurring during the 'encoding' stage of information processing (Terrace, 1963). It can be contrasted with the well-known 'trial-and-error', or 'errorful' learning method in which individuals improve their performance by learning from their mistakes. It is thought that errorless learning works by exclusively strengthening *correct responses* in memory (e.g. McClelland, 2001), and minimizing competition or interference from any possible incorrect responses when one attempts to remember or use the information (i.e. at the 'retrieval' or 'response' stage) (e.g. Baddeley & Wilson, 1994).

Errorless learning has been used with particular success with individuals with ABI (e.g. Wilson et al., 1994), learning difficulties (Sidman & Stoddard, 1967), dementia (e.g. Winter & Hunkin, 1999), and schizophrenia (e.g. O'Carroll et al., 1999). It has been suggested that people with certain cognitive impairments benefit more than neurologically healthy individuals from errorless techniques because they are unable, or less able, to consciously correct errors reinforced implicitly (see Tailby & Haslam, 2003, for a discussion). However, there are differences of opinion surrounding the precise mechanisms underlying the success of errorless learning (e.g. Baddeley & Wilson, 1994; Hunkin et al., 1998; Kessels et al., 2005), discussed in more detail later in the chapter.

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This chapter firstly gives an overview of the history of the errorless learning literature, describing the first study to demonstrate that errors are not vital for learning to occur (Terrace, 1963), and the first studies to apply errorless learning techniques with people. An account of the mechanisms behind errorless learning is then postulated, and the controversial issues in this area are discussed. This is followed by a review of the applications of errorless learning, describing the range of tasks across which errorless learning has been found to confer a benefit. Although some recent studies have begun to investigate the potential of errorless learning for practical tasks, the vast majority of studies are based around verbal learning, and the majority of this chapter is devoted to the verbal learning studies. Studies in which errorless learning has been applied to tasks with more of a practical or spatial bias are then briefly introduced. The application of errorless learning to such tasks is discussed in greater length in Chapter 7, which reports a comparison of errorless and errorful methods in a route-learning task. Finally, studies combining errorless learning with additional learning strategies are briefly introduced. These studies are covered in more detail in Chapter 8, which reports a study comparing simple errorless learning with errorless learning combined with naturalistic route learning strategies.

3.2 History

Errorless learning was first explicitly studied by Terrace (1963), working on operant conditioning paradigms with pigeons. Prior to Terrace's (1963) study, it was widely believed that errors (or, responses to S-, the non-reinforced stimulus) were necessary for learning. Terrace, however, taught pigeons to discriminate a red from a green light, via a completely

error free learning procedure. She did this by introducing (and rewarding responses to) a bright red light first, before gradually fading in a green light, initially for brief intervals and at low brightness, to discourage any erroneous responses. Therefore, rather than making equal numbers of responses to red and green lights, and learning that only red responses earn rewards, the birds were induced to exclusively respond to the red light from the start of training. Interestingly, the birds that learned without errors were actually more accurate in their responding than those permitted to make them.

Sidman and Stoddard (1967) successfully applied errorless learning to people, to teach 19 boys with severe learning difficulties the difference between circles and ellipses. Half of the children were taught using a near-errorless, fading method, and the other half using trial-and-error. A much higher proportion of the children learned the discrimination under errorless conditions than under trial-and-error.

The first study to apply the errorless learning technique to brain injury rehabilitation was that of Baddeley and Wilson in 1994. They compared errorless and errorful methods for a verbal learning task, in which 16 people with brain-injury-related memory deficits and a group of controls without neurological impairment were given word stems (e.g. 'BR----,') and asked to learn the words to which they belonged (e.g 'BR<u>ICK</u>'). Errorful learning trials consisted of the experimenter eliciting two to three incorrect responses from the participant by saying 'I am thinking of a word beginning with BR... Can you guess what that word might be?' before providing them with the correct response and asking them to write it down. Errorless learning trials consisted of the experimenter immediately providing participants with the correct

response, saying 'I am thinking of a word beginning with BR and that word is BRICK', then asking them to write it down. Test trials consisted of the experimenter providing a word stem and asking the participant to recall the word that should complete it. All participants performed better under errorless conditions, and this was particularly pronounced for people with memory impairment.

3.3 Mechanisms involved in errorless learning

Many researchers have attempted to determine whether errorless learning is accomplished via implicit or explicit memory. Although there is some controversy over precisely what constitutes 'implicit memory' (Willingham & Preuss, 1995), it is generally defined as memory that 'does not require conscious retrieval of the past, such as memory for skills (procedural memory), habits (conditioning and habituation), and subconscious processing (e.g., priming and cueing)' (Kessels & deHaan, 2003, p806[1]). Explicit memory, also known as episodic memory, refers, conversely, to conscious recollection of the learning experience and material learned therein.

The fact that numerous studies have found a benefit for errorless over trial and error learning in studies with people with ABI (e.g. Baddeley & Wilson, 1994; Hunkin et al., 1998; Squires et al., 1997) might be seen as indirect evidence that errorless learning works via implicit memory. Because implicit memory is typically spared in ABI (Graf, Squire & Mandler, 1984; Kuzis et al., 1999; Warrington & Weiskrantz, 1974), whereas explicit memory is more often

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[1] It is worth briefly contrasting implicit *memory* with implicit *learning*; implicit learning is defined as learning 'without the information being represented in consciousness at the time that the encoding takes place'. *(Shanks et al., 1994, p837)*. Implicit learning is not necessary for implicit memory. It is possible for an individual, particularly someone with an impairment in explicit memory, to be conscious of learning, and even actively attempt to learn, something which they later only have access to via implicit memory (e.g. Page et al., 2006).

impaired, it is logical to extrapolate that implicit mechanisms may be responsible for the success of errorless procedures. In more detail, Baddeley and Wilson (1994) hypothesise that when an individual's explicit memory is impaired, such that they are unable to consciously recall the learning experience and the feedback encountered, they are forced to rely on implicit or subconscious memory. Implicit memory cannot distinguish accurately between correct and incorrect stimuli, and merely tends to elicit the strongest response, which could be simply the most recently encountered or most often encountered word. However, when the correct word has been encountered more frequently than incorrect competitors, as in errorless learning episodes, it will be more likely that this will be produced at recall.

As a test of the hypothesis that errorless learning exploits implicit memory, some researchers have examined the relationship between the degree of memory severity and the relative advantage of errorless over errorful learning. Findings of a greater benefit for errorless learning in people with more severe explicit memory impairment (e.g. Baddeley & Wilson, 1994; Evans et al., 2000; Riley et al., 2002) suggests that the benefit must be related to reliance upon implicit memory. However, several studies have cited an opposite effect, such as people with relatively spared explicit memory deriving greater benefit from errorless learning than people with more severe memory impairment (Tailby & Haslam, 2003), and younger participants showing greater benefit than older people with age-related memory decline (Kessels et al., 2005); an effect which suggests a role for spared explicit memory. Still other studies fail to find an effect of severity of memory impairment in either direction, with equal benefit being derived by people with mild cognitive impairment and neurologically

unimpaired controls (Akhtar Moulin & Bowie, 2006), and younger and older adults (Kessels & De Haan, 2003(b)).

Tailby and Haslam (2003) theorize that different individuals may process information learned errorlessly via different memory systems, with severely impaired participants relying purely on implicit memory, while relatively unimpaired individuals use both implicit and explicit memory (Tailby & Haslam, 2003). This could explain why their participants with moderate impairment derived greater benefit from errorless learning than participants with severe impairment. However, this does not explain why other studies find that people with particularly impaired memory derive just as much, or more, benefit from errorless learning than people with no memory impairment.

It is possible that variations in tasks and outcome measures used by different studies may account for this inconsistency. For example, on a word-stem completion task, Page et al. (2006) found that errorless learning was equally beneficial for people with moderate and severe memory impairment when the recall test was implicit, i.e. when participants were asked to complete a stem with the first word to come to mind. However, when memory was tested explicitly, i.e. where participants were asked to complete a stem with a previously learned word, the advantage of errorless over errorful learning only held for the group with severe impairment. In other words, where a task can be completed as efficiently by implicit memory as it can by explicit memory, errorless learning may help participants with and without memory impairment to an equal extent. Where explicit memory is important for a task, however, errorless learning may benefit people with impaired explicit memory to a

greater extent than it will benefit people whose explicit memory is intact (although this is not to say that the overall performance of participants with memory impairment will be superior under errorless conditions, just that the *relative* benefit they derive from errorless compared with errorful methods might be expected to be greater).

The idea that individuals with severe memory impairment may have to learn implicitly what neurologically healthy individuals can learn implicitly or explicitly is concordant a theory proposed by McClelland (1995, 2001), derived from principles of Hebbian learning and tested via computational modelling of neural learning. This theory may also, in conjunction with some of the details from Baddeley and Wilson's (1994) study, explain exactly how errorless learning has its effect in people with ABI, and explain why people without ABI sometimes derive benefit from errorless methods. McClelland (1995, 2001) noted that individuals with severe episodic memory deficits due to ABI, particularly hippocampal lesions, are able to acquire certain pieces of information over multiple trials, when presented consistently (i.e. without errors or variability – as in errorless learning). Individuals without memory impairment, by contrast, are able to learn the same information in single trials, or when errors or alternatives were presented during learning, suggesting that different learning systems may be responsible for people with and without ABI. McClelland proposed that the hippocampus (which is particularly susceptible to lesions in brain injury (Geddes, LaPlaca & Cargill, 2003)) is required for fast, episodic learning of information, whereas the necortex learns more slowly, storing information about more consistent relationships. When the hippocampus is damaged, it is possible for the sort of information that is usually acquired via episodic memory (via the hippocampus) to be acquired directly by the neocortical memory system, but

this takes time and consistency. This is because the neocortex does not have the same degree of plasticity that the hippocampus does, and only modifies neuronal connections by small amounts on each learning trial. Therefore, errorless learning may facilitate the gradual modification of connections in neocortex, whereas errorful learning may not allow sufficient consistency and repetition for this to occur.

Evans et al. (2000) also refer connectionist models to explain some of the findings in errorless learning, with reference to Murre (1997) who distinguishes between implicit strengthening of pre-existing associations (as is seen in priming), and acquisition of completely novel information by repetition. Evans et al. (2000) note that this kind of repetition learning is implicit for people with ABI in the sense that they will not recall the time or place where they acquired the knowledge (presumably because learning bypassed the hippocampal structures responsible for normal episodic memory formation), but explicit in the sense that it can be accessed on explicit recall tests.

This theory explains why errorless learning processes, which involve consistent repeated presentation of material across trials, may help people with ABI to retain information that they are unable to learn via errorful methods. It also does not need to rely solely upon the interference from incorrect responses associated with errorful learning to explain the advantage of errorless learning. This is important because Baddeley and Wilson (1994) found that the proportion of repetition errors at recall under errorless learning conditions was no greater for people with memory impairment than it was for control participants (although absolute numbers were greater). In other words, contrary to theories of proactive interference

(Luria, 1966, in Baddeley & Wilson, 1994), people with memory impairment do not fail to learn under errorful conditions because of a particular tendency to reproduce incorrect responses (Baddeley & Wilson, 1994). When an error is produced during learning, a person with memory impairment is only as likely as a person without memory impairment to incorrectly reproduce it at recall. It follows that errorless learning must also facilitate the recall of correct responses in some more direct way to improve performance of people with ABI in particular. The connectionist theory that the consistent repetition of the correct response associated with errorless learning can facilitate the formation of memory in neocortex without access via the hippocampus suggests a way in which errorless learning may function besides through the prevention of competing responses at recall.

If errorless learning benefits people with ABI because it allows for people with impaired one-trial explicit learning to gradually acquire new information (or prime existing knowledge) directly in neocortex, then why does it also result in better performance than errorful learning for people without memory impairment? As mentioned above, people with ABI were no more likely to make perseverative errors at recall following errorful learning than people with intact memory. Both people with and without memory impairment, however, do make a significant number of such errors; Baddeley and Wilson (1994) reported that approximately 80% of incorrect responses were repetitions of previously generated responses. Although people without memory impairment are relatively easily able to acquire items via one-trial learning, they are also likely to forget a certain number of items (albeit a smaller number than are forgotten by people with explicit memory impairment), producing incorrect repetitions

instead. Errorless learning appears to minimise the likelihood of this regardless of the level of memory impairment (Baddeley & Wilson, 1994).

In summary, there has been much controversy over whether errorless learning is sub-served by implicit or explicit memory. Inconsistent patterns of findings, with severity of memory impairment sometimes increasing and sometimes decreasing the magnitude of the benefit derived from errorless learning, make it difficult to reach a single conclusion, although the majority of researchers concede that there must be a role for both implicit and explicit processes in errorless learning (Baddeley & Wilson, 1994; Evans et al., 2000; Page et al., 2006; Tailby & Haslam, 2003). Detailed data on the types of errors made by people with and without memory impairment (Baddeley & Wilson, 1994), analysed in the context of connectionist models of learning with and without explicit memory (McClelland et al., 1995; 2002) can begin to explain, on an operational level, how errorless learning may benefit people with memory impairment who are relatively unable to acquire novel information through errorful learning. In addition, it explains why errorless learning sometimes also benefits people with no memory impairment.

3.4 Applications of Errorless Learning

Having addressed the potential mechanisms behind errorless learning, this section is concerned with the extent of the benefits of errorless learning on a more practical level, and reviews the scenarios in which errorless learning has been successfully applied. As described earlier in the chapter, Baddeley and Wilson (1994) demonstrated that people with and without ABI learned word stem completions better under errorless than errorful conditions. However,

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the practical applications of successfully completing word-stems in such a cued-recall task are limited, and subsequent studies have sought to determine whether errorless methods can be applied to less restricted scenarios.

Squires et al. 1997) examined whether errorless learning could help people with ABI learn novel associations between words, rather than simply strengthening existing associations (e.g. between stems and the words they refer to). They presented remotely associated pairs of words (e.g. 'salad' and 'cold'), and completely un-associated pairs of words (e.g. 'tree', 'plate'), and tested retention after errorless versus errorful learning. Consistent with what might be predicted, extrapolating from findings from Graf and Schachter (1985) of preserved priming for novel associations in amnesia, they found that errorless learning was, indeed, advantageous for both types of word pairs. However, after a delay of one hour, the errorless advantage was only significant for the novel word pairs. The authors suggest that the fact that learning novel word pairs is more difficult than learning remotely associated word pairs may have led to the more long-lasting advantage of errorless learning, through necessitating greater effort and deeper encoding. This is consistent with findings reported in Riley et al.. (2002) that the benefit of pure errorless learning may be more pronounced for difficult tasks, whereas for less challenging tasks the relatively passive nature of errorless learning may reduce its benefit. Another potential explanation comes from Evans et al. (2000), who suggest why verbal material learned errorlessly in their own study is not retained after a delay. They note that the multitude of words encountered every day during the interval between learning and delayed recall may actually interfere with errorlessly learned combinations of words, eliminating the associations established between word stems and the words completing them,

or between pairs of words, and so on. They comment that 'more unusual activities' (Evans et al., 2000, p.98), i.e. those that are not (like words) encountered every day in different contexts, may be more successfully retained over a delay following errorless learning. As the present series of studies assess the learning of routes, which would appear to be a relatively unusual activity (in the sense that the test routes would not be expected to be encountered in different contexts), it would seem that retention of errorlessly learned information has a reasonable chance of being retained across a delay.

Although Squires et al. (1997) demonstrated that errorless learning could be applied to novel associations, they only assessed cued (and not free) recall in the sense that one word from a pair was provided and participants had to recall the associate. Hunkin et al. (1998) therefore, attempted to determine whether errorless learning could help people with ABI to recall information un-cued. They used a word-stem completion task, with the same procedure employed by Baddeley and Wilson (1994), but in addition to testing cued recall via stem completion, they also asked participants to recall words from the list learned without the provision of the stems as cues. They also tested performance after a delay of 48 hours. Whereas, as noted above, Squires et al. (1997) found that the advantage of errorless learning for remote associations dissipated across a delay, Hunkin et al. (1998) found the advantage of errorless learning was maintained over 48 hours. Errorless learning also resulted in superior free recall, although free recall after a delay was at floor level for both errorless and errorful conditions. This suggests that errorless learning results in better cued-recall than errorful learning for a sample of people with ABI, and that this effect is consistent across a relatively long delay. Free recall can also be improved by errorless learning, but only when tested

shortly after learning trials or shortly after delayed cued recall trials have been given. This suggests that the applications of errorless learning may be wider than simply facilitating immediate cued recall, but also suggests that free recall after a delay may be problematic. In order to make practical use of errorless learning, therefore, it may be necessary to incorporate it into situations where cues may somehow be made available at recall.

Learning information that can only be recalled in response to a cue may seem relatively impractical, in the sense that, if a cue must be given, the provider of the cue could just as easily provide the response. However, cues can be built into aspects of the environment in which recall is required. Evans et al. (2000) combined errorless learning of face-name associations with imagery mnemonics that encouraged participants to visualize and trace the first letter of a person's name on the image of their face. In this way, seeing the face provides a first-letter cue to the name, allowing participants to successfully recall it in a process more akin to cued-recall than free-recall, even though nobody has to explicitly provide a cue.

The utility of errorless learning for helping people with memory impairment to recall paired associates has a number of practical applications. As mentioned above, name learning, a task that can be problematic for people with ABI, can be improved by errorless methods (Evans et al., 2000, for further examples see also Clare et al., 1999; Wilson et al., 1994), and some studies have applied errorless techniques to the learning of object names (e.g. Wilson et al., 1994), which may be particularly helpful in the rehabilitation of dysnomia (e.g. Frattali & Kang, 2004).

Errorless learning can also have benefits beyond improving recall of word lists or paired associates, however. Still within the domain of verbal learning, Glisky and colleagues have demonstrated the potential of a technique very similar to errorless learning for training individuals with memory impairment in computer use (e.g. Glisky, Schachter & Tulving, 1986a, 1986b; Glisky, 1992). With the method of vanishing cues, an incremental learning method that minimises errors, they were able to teach people with memory impairment definitions of computer-related vocabulary (Glisky et al., 1986a). They then went on to demonstrate that semantic knowledge about procedures involved in operating a computer could be acquired by the same method, and that the knowledge could be put into practice in operating a computer (Glisky et al., 1986b). Perhaps most impressively, Glisky (1992) applied the procedure to a vocational data-entry task, where participants learned instructions for a data-entry job and put them into practice in the execution of the job. Using a purely errorless procedure, Hunkin (1998) achieved similar results, training a person with ABI to use various computer commands within the programme 'Microsoft Word,' such as 'edit' and 'file'. It is possible that the menu-driven nature of computer use contributed to the success of errorless learning in these scenarios, based on the argument above that errorlessly learned material may be recalled better after a delay when a cue is provided or embedded in the environment in which recall is required.

The effective learning of semantic material (such as what an invoice number is or what the command 'file' does) and its subsequent application to practical tasks seen in the aforementioned studies appears to fit the definition of implicit repetition learning provided by Evans et al. (2000), in that novel semantic material is learned effectively without any detailed

recollection of the learning episodes (Glisky, 1992). The impressive potential of errorless learning for teaching people with explicit memory deficits novel semantic information is tempered by a few practical constraints, however. A considerable number of repetitions of learning trials are typically required before material is learned, and the learned material can be 'hyperspecific' (e.g. Bayley & Squire, 2002; Glisky et al., 1986), which means that it is inflexible and vulnerable to changes in format or phrasing of information. Having said this, Glisky et al. (1992) found less hyperspecificity when participants' response to changes in stimuli was assessed procedurally, by performance on a data entry task, than when it was assessed explicitly, by verbal responses to probe questions. Furthermore, Stark, Stark and Gordon (2005) found that hyperspecificity can be reduced by introducing variation during learning trials. In other words, although there are practical constraints that limit the benefits of errorless learning of novel semantic information on a large scale, they are not insurmountable and there is certainly evidence that errorless (or minimal error) techniques can help people acquire sufficient information to carry out useful tasks.

While the studies of Glisky and colleagues (1986a; 1986b; 1992) and Hunkin (1998) provide good evidence for the value of errorless learning for the acquisition of novel information and the learning of practical tasks, however, they do not compare performance after errorless learning with performance after any alternative learning technique. However, the idea that errorless methods resulted in better performance than errorful methods would have done is supported by a single case study by Wilson et al. (1994), who compared errorless and errorful methods for teaching a person with memory impairment to programme an electronic organiser and confirmed that the errorless way resulted in the best recall.

More recently, Evans et al. (2000) assessed the benefits of errorless learning for practical tasks, including the programming of an electronic organiser, with group samples. They failed to replicate the benefit of errorless learning for programming an organiser, and also failed to find any benefit of errorless learning for spatial learning tasks. The lack of a significant benefit for errorless learning in the organizer task in Evans et al. (2000) could indicate that errorless learning is a technique that benefits some, rather than all, individuals. Evans et al. found some evidence to support the notion that the greater an individual's [explicit] memory impairment, the greater the benefit of errorless over trial and error learning, presumably because they are more reliant upon implicit memory. This could mean that across a heterogeneous sample of people with memory impairment, the benefit of errorless learning may not reach significance, although it may well be of considerable value to those individuals within the sample whose memory is sufficiently impaired that they fail to learn via trial and error.

In addition, the fact that a large meta-analysis of studies by Kessels and deHaan (2003) found errorless learning to be significantly superior to trial and error supports the decision to continue assessing the benefits of errorless learning across various tasks, despite the less optimistic results from Evans et al. (2000).

Of particular relevance to the present series of studies are two comparisons of errorful and errorless route-learning reported in Evans et al. (2000). The findings from these comparisons and their implications are discussed in greater detail in Chapter 7, which is specifically

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concerned with the literature on errorless learning spatial information. In brief, however, Evans et al. failed to find an advantage for errorless over errorful learning for the route learning tasks, suggesting that the benefits seen in studies of verbal learning for errorless methods may not extend to practical spatial tasks. However, there are several other explanations for the lack of effect, including the fact that errors may have been introduced in the errorless condition throughout the test trials. There is also a possibility that participants with executive deficits who formed a relatively large proportion of the study's participants (50%) may have, for some reason, derived limited benefit from errorless learning. Pitel et al. (2006) recently advanced a theory that severe executive dysfunction may limit the benefit people gain from errorless learning, based on two case studies in which one patient with severe executive dysfunction derived much less of a benefit from errorless learning than a patient with mild executive impairment, despite the fact that the latter had greater memory impairment. The question of whether executive function influences a person's ability to learn via errorless methods is addressed in Chapter 9. In addition, the route-learning task used by Evans et al. (2000) involved memorising a sequence of moves across a two-dimensional pattern of stepping-stones, which is quite far removed from the route learning tasks used in the present series of studies, which are set in a three-dimensional large-scale virtual environment. This difference suggests that the lack of benefit for errorless learning observed by Evans et al. (2000) should not necessarily predict a lack of any errorless learning advantage in the present studies. All of these issues are discussed in more depth in Chapter 7.

Finally, of particular relevance to the study reported in Chapter 8 (which explores the potential for increasing the benefit of errorless learning by combining it with additional

strategies) are studies that have gone beyond the use of errorless learning as a stand-alone aid. Evans et al. (2000), for example, combined errorless learning with visual imagery mnemonics and saw enhanced recall compared with errorless learning alone. Squires et al. (1997) and Tailby and Haslam (2003) successfully used errorless learning alongside a learning procedure that encourged participants to generate their own associations between words (rather than providing then with the associations). Kalla and Downes (2001) used errorless learning and also pre-exposed participants to the material they were to learn, and found increased benefits at recall. All of these findings suggest that the benefit derived from errorless learning can potentially be enhanced by combining it with additional learning techniques. The study reported in Chapter 8 assesses whether naturalistic techniques used by people in their everyday route learning may also improve the benefit of errorless learning, and discusses all of these findings in more detail. Several theoretical models that predict enhanced performance with additional strategies are also introduced.

3.5 Summary

In summary, errorless learning has been show to be more effective than errorful learning for both people with and without ABI, although it is of particular importance for people with ABI as they are more often in need of memory techniques to improve recall of learned information. There is little consensus as to what mechanisms support errorless learning (or, more precisely, what mechanisms are responsible for the advantage of errorless over errorful learning), although a majority of researchers now seem to agree that both implicit and explicit memory play a role. Consideration of error data reported by Baddeley and Wilson (1994) and

a connectionist model of errorless learning (McClelland, 1995; 2002) may begin to provide a more specific model for the precise way in which errorless learning benefits people with ABI.

The majority of studies of errorless learning have assessed verbal learning, and errorless methods can result in better performance on word-stem completion tasks, word-list learning, learning of face-name associations and learning of object names. The benefit of errorless learning has been found, by some studies, to persist after delays of several months, although other studies find that the benefit disappears after a matter of minutes. Errorless learning appears to be particularly suited to helping people recall information at cued recall, but some studies have also found good free recall of errorlessly learned information. With enough repetition of learning trials, it seems that errorless and minimal-error procedures can even be used to help people with severe explicit memory deficits learn novel semantic information and put it to use in practical, vocational tasks such as computer data-entry. There have been relatively few studies of errorless learning of spatial information. What appears to be the only study to assess errorless route learning in ABI failed to demonstrate a benefit for errorless over errorful methods, but the lack of effect could be attributable to a number of factors, and further investigation of the potential for errorless learning of spatial information seems warranted. Several recent studies suggest that the benefit derived from errorless learning might be further increased by combining it with specialised learning techniques. Whether naturalistic strategies can also improve errorless learning remains to be seen. The studies reported in chapters 7 and 8 address the questions of whether errorless learning is superior to errorful learning in complex, realistic route learning; whether combining errorless techniques with naturalistic route learning strategies results in further improvement of performance. The

study reported in 9 addresses, amongst other questions, whether there is a link between performance on a range of neuropsychological tests and the benefit derived from errorless learning.

CHAPTER FOUR

VIRTUAL REALITY LITERATURE REVIEW AND INTRODUCTION TO METHODOLOGY

4.1 Introduction and overview

Scultheis and Rizzo (2001) define virtual reality (VR) as 'an advanced form of human-computer interface that allows the user to "interact" with and become "immersed" in a computer-generated environment in a naturalistic fashion.... in three dimensions' (Scultheis & Rizzo, 2001, p298). Most people have probably experienced VR primarily in the field of entertainment (Livingstone & Bober, 2004), with commercial videogames becoming increasingly popular. The practical applications of virtual environments stretch far beyond pure recreation, however, and are discussed during the course of this chapter, which provides evidence for the ecological validity of VR: in general settings; in the field of wayfinding; and for research with people with ABI. This is followed by a discussion of the advantages afforded by VR in the same three settings. Different types of VR are then compared, with an account of the particular hardware and software choices made for the present series of studies followed by an introduction to that hardware and software.

4.2 Ecological validity of virtual reality

One of the most important considerations in the use of VR is its ecological validity. Ecological validity, or the 'relation between real-world phenomena and the investigation of

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these phenomena in experimental contexts' (Schmuckler, 2001, p420) generally varies inversely with experimental control, but virtual environments appear to offer one of the best available trade-offs between the two constructs (e.g. Loomis et al., 1999). It is the combination of good ecological validity and various practical advantages over the real world that makes VR a good substitute, under many circumstances, for real world scenarios.

While most virtual simulations look very authentic (see figure 4 for a screen-shot of a typical scene from the programme used in the present series of studies), empirical proof of their ecological validity is, of course, also desirable. Such evidence comes in several forms, of which the most common are 'equivalence,' and 'training' or 'transfer' studies.

Equivalence studies are those that demonstrate that some aspect of performance in a virtual simulation is equivalent to performance in an analogous real world scenario. These can be simply findings of equal scores on performance in a virtual and real version of a task (e.g. Titov and Knight, 2000). Equivalence is also suggested by studies in which individuals' real-world deficits are mirrored in a VR situation. (e.g. Skelton et al., 2000). Training and transfer studies typically attempt to teach an individual something within a virtual world, such that their performance in an analogous real world task will improve as a result. Some studies simply assess real-world performance before and after virtual training, whilst others compare virtual training with other forms of training, such as real-life training, or training via pictorial or written instructions (e.g. Witmer, Bailey & Knerr, 1995, in Darken & Peterson, 2001). Evidence from training and transfer studies not only supports the ecological validity of VR, but also demonstrates its practical utility as a training tool.

Another potential source of evidence for the equivalence of virtual and real world task performance is data from imaging studies. Several studies have demonstrated the activation, during performance of virtual tasks, of brain regions implicated in the execution of corresponding real world tasks (e.g. Maguire et al., 2003)

4.2.1 Ecological validity of virtual reality in general applications

One of the first practical applications of VR was in training fighter pilots (Prather, 1971), and training transfer from virtual to real world settings has been consistently demonstrated in flight training. From a meta-analysis of 26 studies, Hays, Jacobs, Prince and Salas (1992) concluded; 'simulators combined with aircraft training consistently produced improvements… compared to aircraft training only' (p.63). The ecological validity of virtual flight simulations is implicit, in this case, in their demonstrated effectiveness in training people for real world flights. Similarly, evidence for the transfer of skills from virtual to real world environments is seen in the field of medicine, where surgeons are trained with high effectiveness in procedures using VR (e.g. McCloy & Stone, 2001).

In a direct test of the equivalence of virtual and real world training, Rose et al. (2000) employed a 'steadiness tester' task. Participants practised guiding the eye of a metal wand around an irregularly shaped piece of metal without allowing the two to touch. There was no difference in real-world testing in performance between a group who practised using an immersive virtual version of the task and a group who used the real apparatus, suggesting that the virtual training was as effective as real world training. Furthermore, virtually trained

participants were actually less susceptible to concurrent-task interference during testing, possibly because VR training was somewhat more difficult, resulting in deeper encoding and more robust learning, suggesting that virtual training can even surpass real world training in certain circumstances. It is worth noting that all the demands of the real-world task in this study were remarkably similar to those of the virtual training procedure, so where the virtual and real world versions of a task are more divergent results may be less impressive.

However, there is evidence for the ecological validity of virtual simulations less directly comparable to their real life counterparts. Cromby et al. (1996) employed a non-immersive virtual simulation of a supermarket which was 'very simple... [with] limited resemblance to the real supermarket' (p.106) to teach teenagers with severe learning difficulties shopping skills. Compared with control participants who interacted with a non-relevant virtual simulation, those who trained in the virtual supermarket showed superior performance when tested in a real world supermarket task.

4.2.2 Ecological validity of virtual reality in wayfinding research

Witmer, Bailey, Knerr & Parsons (1996) explored the usefulness of a simulated office for teaching participants the layout of its real-world counterpart. Training in the immersive virtual office did not result in as many correct turns at testing as real-world training, but did result in better performance than verbal training, demonstrating that useful spatial knowledge of a real space can be attained through exploration of a simulation of that space.

Hunt, Arch & Roll (1987) (in Stanton, Foreman & Wilson, 1998) found that video footage of a building was as effective as visiting the real building for familiarization purposes, with participants showing similar amounts of confidence, wayfinding performance and internal representations of the environment whether trained in the real or in the video setting. While video footage may not meet all the criteria of 'virtual reality', there is a good deal of similarity between the two types of exposure, such that this study provides indirect support for the ecological validity of VR.

Additional studies demonstrating the ecological validity of VR in wayfinding research are discussed in Chapter 5, where pilot data directly comparing performance on a VR and real world outdoor route-learning task.

4.2.3 Ecological validity of virtual reality in research with populations with acquired brain injury

Studies in which the real-world wayfinding impairments of people with ABI are reflected in virtual environments (Skelton et al., 2000; Spiers et al., 2001) support the ecological validity of VR both as a tool for wayfinding research, and in ABI research. Incidentally, the value of this clinical sensitivity is highlighted by the comparatively poor ability of traditional 'pencil-and-paper' psychometric tests of spatial ability to predict wayfinding performance in people with ABI (e.g. Nadolne & Stringer, 2001),

With a sample of people with ABI, Titov and Knight (2000) found that performance on a VR shopping mall test of prospective memory was highly equivalent to performance on a real-

world version of the task, with correlations of .80, demonstrating good validity of virtual environments as assessment tools.

Similarly, Spiers et al. (2001) found good consistency between typical real world performance patterns and performance in a VR town for participants with temporal lobectomy. Participants with left hemisphere lesions were more impaired in episodic memory tasks, while those with right temporal lobectomy were impaired on tests of topographic memory. This is consistent with real-life observations of spatial deficits following right temporal lesions (e.g. Smith & Milner, 1981, in Spiers et al., 2001) and of verbal memory deficits following left temporal lobe lesions (e.g. Frisk & Milner, 1990, in Spiers et al., 2001), and provides support for the validity of virtual environments with participants with ABI related memory impairment. This study is particularly relevant to the studies reported in this thesis, as both employ a VR town found within commercial videogame.

Skelton et al. (2000) found performance deficits consistent with participants' real-world impairments in a more abstract wayfinding task. They created a computer-generated version of the traditional Morris water maze, consisting of a circular arena inside a square room, in which the aim is to locate a hidden target based upon spatial cues taken from the walls of the room. Impaired performance on the virtual task was consistent with participants' reported real-life wayfinding difficulties. As the authors comment, this finding is 'preliminary evidence that people with TBI have long-lasting deficits in spatial learning and memory that produce impairments in performance in virtual space.' (Skelton et al., 2000, p171).

Brooks et al. (1999) put VR to practical use by employing a virtual simulation to teach a patient with severe memory impairment routes around the hospital in which she was a long-term inpatient. She was unable to learn routes after multiple attempts in the real world, but learned several routes effectively through training in the virtual simulation and transferred this knowledge successfully to the real world environment.

There is a good deal of support, therefore, for the ecological validity of VR in a range of scenarios including wayfinding tasks. Several studies have also found virtual environments to be sensitive to the real-world impairments of participants with ABI, and there is even evidence for the ecological validity of videogame based environments, of the kind employed in the present series of studies. While this attests to the validity of VR as a training and assessment tool in general, given the broad range of virtual environments available and the variability between them, it seems prudent to also assess each simulation upon its own merit. The first experiment reported in this thesis (Chapter 5), therefore, compares route-learning performance observed in the virtual environment used in the present series of studies with real-world route learning.

4.3 Practical advantages of virtual reality

4.3.1 General practical advantages of virtual reality

While the previous section discussed the equivalence of the real-world and VR, certain differences from the real world are actually responsible for some of VR's practical advantages. For example, a virtual environment can be manipulated to incorporate or exclude

various stimuli, or to increase or decrease their salience. This is of particular benefit in psychology research, and can also be put to use in practical applications. While some VR simulations may seem less engaging than the real world, others may seem more engaging, and each of these scenarios can be beneficial.

In the treatment of phobias, for example, individuals who find their phobic stimuli too aversive to engage in real-world exposure therapy are more amenable to VR therapy because stimuli are less threatening (Garcia-Palacios et al., 2001). Conversely, Padgett et al. (2006) found simulated fire safety training with children with cognitive impairments more efficient than real world training, because it was, in this case, more engaging than real world fire drills. The present study did not expect to benefit particularly from increased or decreased salience in the VR route-learning task (compared with real world route-learning), although it is possible that some participants who reported feeling anxious in real world wayfinding situations would benefit from reduced anxiety within the virtual environment, where there are not real consequences of becoming lost.

In psychology research, another key benefit of VR is that it allows participants to engage in a large range of simulated activities whilst remaining largely static. This provides the unique opportunity for brain imaging to be conducted in possibly the closest possible scenario to the real world; As Hoffman, Richards, Coda, Richards and Sharar (2003) observe, 'combining VR and fMRI could potentially lead to a better understanding of the relation between what people are thinking and experiencing, and their associated patterns of brain activity' (Hoffman

et al., 2003, p.130). Whilst brain imaging is not carried out in the present studies, there is great potential for this in future work.

An advantage of VR when used as a training tool is the opportunity to practice, without consequences, tasks that would in the real world be potentially dangerous. The training of pilots (Hays et al., 1992) and surgeons (McCloy & Stone, 2001) in VR is a good example of this. VR in surgical training (and in the training of numerous tasks) also affords greater convenience than real-world training, allowing for multiple rehearsals at convenient times of operations encountered rarely and unpredictably in the real world.

 Cost-effectiveness is another general benefit of VR. In flight training, for example, large fuel costs are saved by using VR. While route learning is not a task that is as difficult to schedule conveniently in the real world, nor a particularly expensive task, it was estimated that using a virtual environment for the present series of studies would increase convenience and decrease costs through avoiding the need to transport participants to novel environments.

4.3.2 Practical advantages of VR in wayfinding research

The unique potential of VR to allow for brain imaging to be conducted whilst participants engage in a range of tasks whilst static, mentioned above (Hoffman et al., 2003), may be of particular utility for wayfinding research, where there is controversy over the cortical areas involved in various processes such as cognitive map storage (e.g. Larkin, 1999; Maguire et al., 2003; Spiers et al., 2002). In studying wayfinding, the manipulability of virtual environments is also an asset. Because it is possible to design environments in which only

certain types of cues are available (e.g. Jacobs et al., 1997; Mallot et al., 2002) VR can assist researchers in the deconstruction of wayfinding into component cognitive processes.

Another practical advantage of VR in the field of wayfinding is that it allows for terrain familiarisation where it might be dangerous to go in person, for example in military manoevres, and it can allow for exploration of larger areas within a given time than would be possible within the real world (e.g. Darken & Banker, 1998).

4.3.3 Practical advantages of virtual reality in research with populations with acquired brain injury

The potential for achieving more within a given time in VR than the real world is of particular relevance for studies with participants with ABI that employ the rehabilitation technique of errorless learning. Errorless learning, as described in Chapter 3, requires multiple consistent repetitions of learning trials, and greater speed at which one can travel in a virtual environment allows for more practice within a given time.

Studies have also highlighted the potential value of VR as an assessment tool, which may allow more ecologically valid measures of various cognitive abilities (including wayfinding performance) in participants with ABI than pencil and paper tasks. Rizzo et al. (2002), for example, created a virtual classroom programme that was effective in identifying attention deficit hyperactivity disorder in children through their interaction with it.

For tasks involving travelling long distances, VR environments can be more practical than real world environments, particularly for participants with mobility impairments. This advantage is of relevance to studies with participants with ABI, who may have restricted mobility or may suffer from fatigue when required to travel for a long distance within a real world environment. Several of the participants in the present series of route-learning studies would not have been easily able to participate in a real-world version of the task, due to restricted mobility.

The safety value of virtual environments can also be particularly beneficial in some cases for participants with ABI. Katz et al. (2005), for example, used VR as a safer option than a real world environment in training people with visual neglect in strategies for crossing the road. In addition to the safety value of the virtual environment, its manipulability allowed for gradual increases in task difficulty, allowing incremental learning. The present studies did not manipulate the virtual environment, because it was important to keep the task as similar to a real world route as possible in order to maximise the generalisability of the results to real world situations, but the safety afforded by the VR environment could be considered an advantage, avoiding any risks of tripping or falling, particularly for participants with impaired coordination as a result of ABI.

4.4 Virtual reality hardware and software

There are two main categories of virtual simulation, 'immersive' and 'non-immersive.' Immersive VR, as the name suggests, aims to induce a feeling of being physically immersed within the simulated environment; experiencing what is sometimes referred to as

'telepresence' (e.g. McCloy & Stone, 2001, p912). This is usually achieved by presenting visual stimuli that cover the whole, or most, of the 360-degree visual field, to mimic the full range of views available in the real world. Non-immersive VR, also sometimes referred to as 'desktop' VR, presents three-dimensional environments via a single flat, two-dimensional screen, such as a television, projector, or computer monitor, through which movement is usually controlled using a mouse, keyboard, joystick, or control pad.

The main advantage of immersive VR over non-immersive is the sense of presence that it affords, as it creates an environment and interaction process more similar to real life than does non-immersive technology. However, certain difficulties encountered more commonly with immersive than non-immersive displays actually endanger the very sense of immersion for which they aim. A time delay sometimes experienced when converting actual movement into changes in the virtual display can reduce a person's perceived 'presence' (e.g. Barfield & Hendrix, 1995).

A 'very significant disadvantage' (Loomis et al., 1999, p 560) of immersive VR is the possibility of negative side-effects such as 'sore eyes, headaches and motion sickness' (Cutmore et al., 2000, p.224), whereas non-immersive environments do not appear to elicit such reactions. Such risks should be considered particularly carefully when participants may be considered in some way vulnerable. Brown et al. (1998) decided against immersive technology for their study with people with learning difficulties, arguing that 'there are still too many unresolved health questions associated with head mounted displays to risk exposure on a group with such specialized needs (Wilson, 1995)' (Brown et al., 1998, p13).

Participants with ABI may also be defined as having certain specialized needs, and the use of equipment with the potential to elicit unpleasant effects raises ethical issues, particularly where a good case can be made for the efficacy of non-immersive technology.

Indeed, a case certainly can be made for the efficacy of non-immersive VR. However, there is one disadvantage of non-immersive VR (in fact, of all but the most advanced systems of even immersive VR) particular to the study of wayfinding to address. 'Dead-reckoning', as introduced in Chapter two, is a strategy usually informed by visual, kinaesthetic and vestibular input, and is therefore compromised in a non-immersive virtual environment. The majority of VEs can produce neither kinaesthetic nor vestibular cues, and visual cues are incomplete in non-immersive environments. However, there is evidence that it is possible to perform 'dead-reckoning' without these cues, albeit perhaps with somewhat reduced accuracy. Riecke, VanVeen and Bülthoff (2002) demonstrated that optic flow alone was sufficient to allow reasonably successful performance, even for participants inexperienced in virtual navigation. When landmarks were also available, performance was almost perfect, even though kinaesthetic and vestibular feedback were still completely absent.

Aginsky et al. (1997) express a lack of concern for the absence of physical feedback in their VR study of route learning in a driving simulator, arguing that 'vision tends to override idiothetic information when the two are in conflict.' (Aginsky et al., 1997, p319), citing as an example the sensation of motion invoked when standing on a railway platform as a train passes. Therefore, whilst the lack of physical feedback is something of a disadvantage to non-immersive VR, it does not appear to be a major obstacle.

One of the most obvious practical advantages on non-immersive VR is cost, with most research institutions already possessing PCs, and games consoles which can produce impressive visual displays (such as the Sony Playstation 2, used in the present series of studies) being available for a fraction of the cost of immersive VR systems. Ease of operation is another advantage of non-immersive VR, making it accessible to researchers without experience of complex computer technology. Finally, portability of non-immersive VR systems is typically much greater than that of immersive ones.

Furthermore, the practical advantages of non-immersive VR do not seem to be overshadowed by relatively poor ecological validity. Several research groups have already demonstrated that 'less immersive systems produced encouraging results' (Rizzo et al., 2004, p207). Of particular relevance is the study of Koh et al. (2000) (in Darken & Peterson, 2001), which actually compared the use of the two types of VR in a wayfinding study, and found no difference in performance on a test of survey knowledge between individuals trained on the layout of a building via a desktop virtual simulation and those trained in an immersive virtual simulation.

Further examples of studies which do not directly compare immersive and non-immersive systems, but have used non-immersive VR with considerable success, include Cromby et al.'s (1996) study using a virtual shopping mall to train individuals with learning difficulties on a shopping task, and Spiers et al.'s (2001) finding that a desktop simulation of a relatively

simple virtual town could distinguish between participants with right versus left temporal lobectomy.

Because non-immersive VR is both practical and effective, therefore, it was seen as an ideal choice for the studies reported in this thesis, and consequently selected over immersive technology. The practical benefits were deemed important not only for the running of the present series of studies, but also with regards to the potential future applications of the research findings.

4.5 Virtual reality hardware and software used for the present studies

The present study employed the relatively portable (at 1.8kg) and affordable (at under £200) 'Playstation 2' games console, manufactured by SONY. This console was also selected for the quality of the visual display produced, for the ease of operation, and for its compatibility with the chosen software. The Playstation 2 links up to any television with a SCART lead, and plays software discs. The user interacts with the virtual world, displayed on a television screen, via a 'control pad' that features (in addition to other non-relevant buttons) two analogue miniature joystick-like buttons, one for changing one's view (as if turning or tilting one's head), the other for moving through the environment.

The software was chosen from a wide selection of commercially available computer games created for the entertainment industry, as this sector actually produces some of the most sophisticated visual displays available (Lewis & Jacobson, 2002). Versions of commercial

videogames have been used successfully in psychological wayfinding research by both Maguire and colleagues (e.g. Aguirre & D'Esposito, 1997; Maguire et al., 1998; Maguire et al., 2003; Spiers et al., 2001).

Several computer games were considered for use in the present studies, with consideration given to the complexity and realism of the environments, ease of controlling navigation, and quality of the visual simulation. The final choice was a game called 'Driv3r', produced by Reflections ltd., an ATARI studio. Driv3r as sold commercially is designed as an adventure game, but can also be used in a mode in which the user is free to walk or drive around the town at their own pace uninterrupted, which was employed in the present studies. Of three town simulations available, one based upon Nice, France, was used in the present route-learning studies, as it was considered to be the most analogous in terms of structure and landmarks to typical UK towns.

The map of virtual Nice reproduced in figure 1 demonstrates the town's layout. In Chapter 5, maps of a virtual route around Nice and a real-world route around Birmingham, UK, also serve to illustrate the reasonable likeness of the road layouts in the UK and France. Comparison of figure 1, the map of virtual Nice, with figure 2, a genuine map of the central region of real-world Nice, also shows the fidelity of the virtual simulation, attesting to its ecological validity.
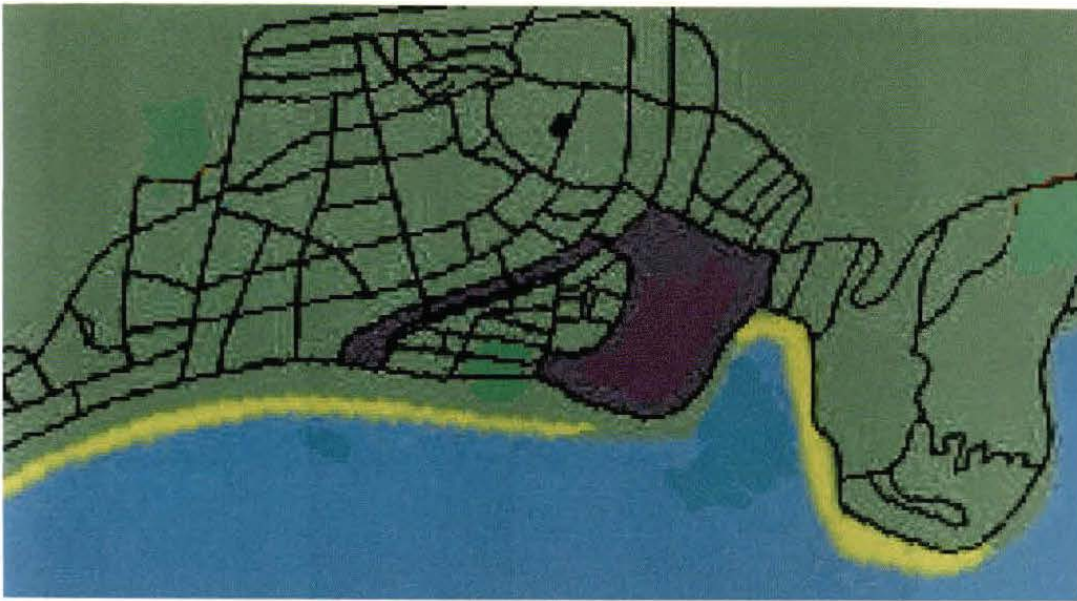
Figure 1: Map of the virtual reality simulation of Nice
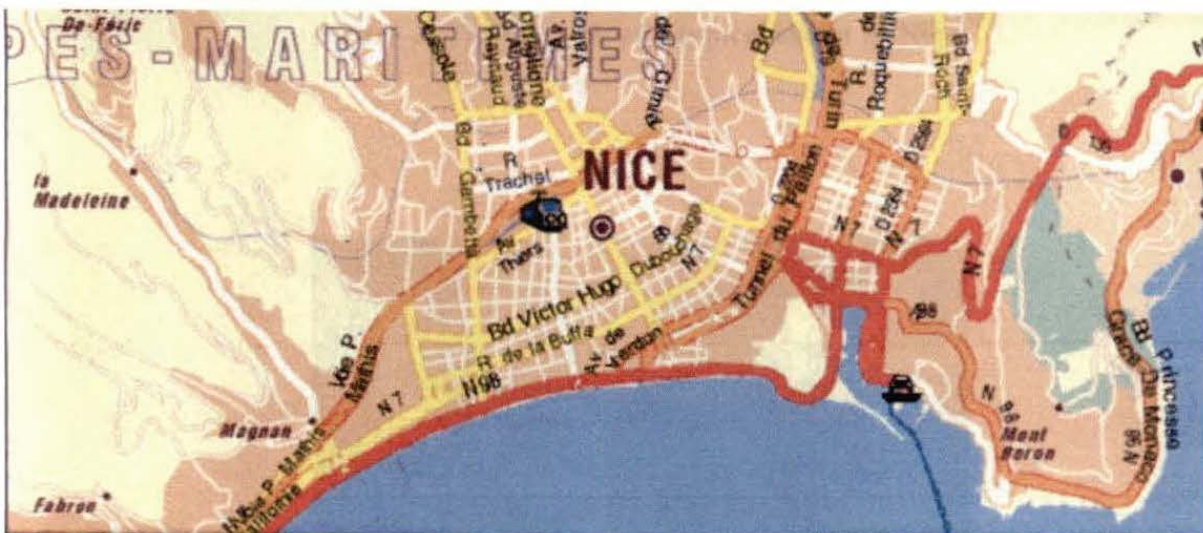
Figure 2: Real-world map of Nice.

In addition to the street layout of the virtual town being very consistent with the real town's configuration, the streets and buildings in the simulation also bear good resemblance to the real town, as demonstrated in figures 3 and 4, which show a photograph from Nice itself and a screen-shot from the virtual town, respectively.
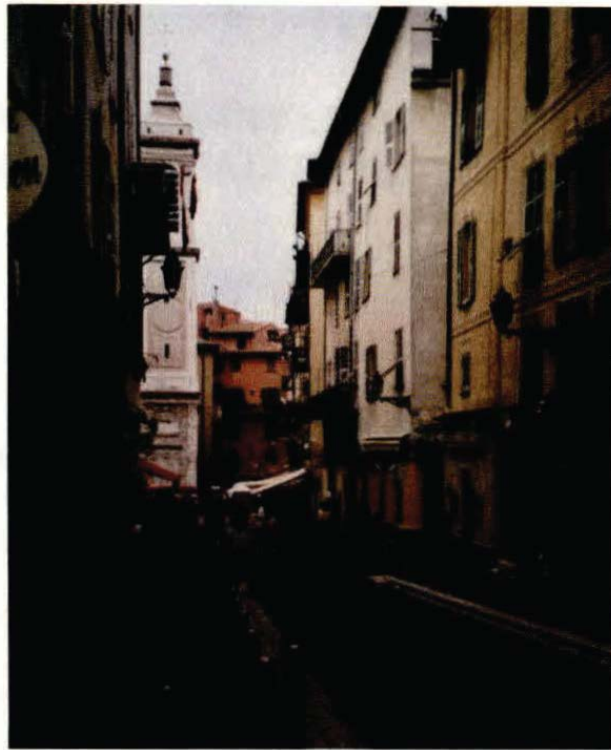
Figure 3: Photograph of a typical street in Nice

Figure 4: Screenshot of a typical street in the virtual town

CHAPTER FIVE

PILOT STUDY ONE: EQUIVALENCE OF REAL-WORLD AND VIRTUAL REALITY ROUTE LEARNING

5.1 Introduction

As discussed in the Chapter 4, the applications of VR are wide-ranging: It has been embraced as a training tool in industries where real world training is dangerous, impractical or costly (e.g. Williams et al., 1997, in Darken, Allard & Achille, 1998); as a reliable assessment tool (e.g. Pugnetti et al., 1995; Rizzo et al., 2002); and as a powerful arena for psychological research (e.g. Hoffman et al., 2003; Maguire et al., 2003). It approximates real life in many important ways (i.e. has good ecological validity), yet offers an environment free from many undesirable aspects of real life, such as random variation, physical dangers and practical constraints (Loomis et al., 1999).

Evidence for the ecological validity of VR comes from studies demonstrating transfer of learning from virtual to real scenarios (Rose et al., 2000, Hays et al., 1992), and from studies finding equivalence of performance in real and virtual versions of a task (e.g. Ruddle, Payne & Jones, 1997; Zhang et al., 2003). The mirroring of real-world cognitive impairments of individuals with ABI in virtual tasks (Skelton, Bukach, Laurance, Thomas & Jacobs, 2000; Spiers et al., 2001; Titov & Knight, 2000) provides further support for the ecological validity of VR, and is of particular relevance to the present series of studies into route learning in ABI.

As mentioned in Chapter 4, VR has been embraced in the field of wayfinding, with particular focus on transfer of learning from a virtual to real world environments, perhaps because this is the most practical application. Wilson and colleagues have demonstrated, in several studies, transfer of knowledge about the layout of a school building from a virtual simulation to the real-world building itself in children with mobility impairments (e.g. Stanton, Foreman & Wilson, 1996; Stanton et al., 2000; Wilson, Foreman & Tlauka, 1996). Not only was training in a virtual school able to improve participants' real-world performance on the specific wayfinding tasks they rehearsed therein (Wilson, Foreman & Tlauka, 1996), it also resulted in generalised improvement on non-trained tasks (Stanton, Foreman & Wilson, 1996; Stanton et al., 2000), suggesting that participants had formed a comprehensive mental model of the real world environment through interacting with the virtual simulation. Furthermore, the improvement that exposure to the virtual school brought about could not be replicated when participants were given a physical, scale model of the school in its place (Foreman et al., 2003). This suggests that the improvement was due to unique features of the VR simulation, and not solely an effect of exposure to information about the layout of the building.

In an outdoor orienteering task, Darken and Banker (1998), studied the knowledge of real world environments gained from prior exposure to VR simulations, in order to investigate the potential of VR as a terrain familiarisation tool for military personnel. They found that for some participants (the 'intermediate' standard navigators), pre-exposure to the environment in the form of a virtual simulation resulted in better performance than pre-exposure to a map or even exposure to the real world itself. This demonstrates, again, that a virtual simulation of an environment can furnish the user with knowledge that can be put into practice in the real

version of that environment. Because a map was provided in all learning conditions, however, it is not possible to determine from this study whether the virtual environment alone would have provided participants with useful spatial information, although it does demonstrate that it is possible to acquire enough information through VR to enhance learning.

Farrell et al. (2003) found that transfer occurred from a virtual simulation of a building to the real building, in a task that involved finding coloured balloons, both with and without a map. This extends the findings of Darken and Goerger (1999) by demonstrating that VR experience alone can improve spatial knowledge of the real world environment. Farrell et al. (2000) do note that the improvement brought about by exposure to the virtual simulation is no greater than improvement brought about by exposure to a map, but this could be because their sample size of 10 participants per condition was too small to detect an effect of the map versus virtual environment. It is also possible that the map was a sufficient learning aid because the environment to be learned was a fairly simple one, consisting of only eight rooms, whereas in a larger or more complex environment the information provided by virtual navigation would be more beneficial. This is consistent with the aforementioned findings that in larger buildings such as whole schools VR is a more effective training aid than a static model (Stanton et al., 2002) and that in large, outdoor environments VR, when used by people of particular competence levels, is more useful than maps alone (Darken & Goerger, 1999).

Regardless of precisely how effective VR is as a training tool in comparison with other methods, there is consistent evidence from Darken and Goerger (1999), Farrell et al. (2003), and Stanton and colleagues (e.g. 1998, 2000) that information about spatial layout learned in a

virtual environment transfers effectively to the real world version of that environment, resulting in improved performance.

Other studies have demonstrated equivalence of wayfinding in real and virtual environments, rather than studying potential for direct transfer of learning from one to the other. Ruddle, Payne and Jones (1997) present a case for similar patterns of the development of spatial knowledge in real and virtual buildings. They gave half of their participants a floor-map of a large office block to study, while the other half were given an extended period in which to navigate around a VR version of the same office block. Upon testing participants' resultant spatial knowledge of the office block, they found a pattern of results consistent with that reported in a similar study carried out in the real world by Thorndyke and Hayes-Roth (1982). Thorndyke and Hayes-Roth (1982) compared the spatial knowledge that office employees developed through frequently navigating around in their building with the knowledge newcomers acquired through studying a floor-map of the office block. Both Ruddle et al. (1997) and Thorndyke and Hayes Roth (1982) found that those who learned by navigation were better at making estimations of the actual walking distances between points along the route than of the Euclidean (or 'as the crow flies') distances between points. Conversely, those who learned by studying a map were better at making Euclidean estimates than estimates of on-foot distances, both in the real world (Thorndyke & Hayes-Roth, 1982) and in the virtual world (Ruddle et al., 1997). Although neither of these studies assessed the development of environmental knowledge in both the real-world and VR in a single set of participants, the comparison of the patterns across studies suggests, indirectly, that the mode

in which an environment is encountered influences development of spatial knowledge in a similar way in VR as it does in the real world.

Several studies of participants with ABI demonstrate equivalence between real and virtual wayfinding, in the form of the mirroring of real life deficits in virtual environments. Skelton et al. (2000) found that 8/12 of their participants with ABI experienced significant difficulty in a virtual version of the Morris water maze (a basic navigation task cued by distinguishing features in the environment), and that performance correlated inversely with patients' self-reported everyday wayfinding difficulties in real life. This demonstrates that navigating even relatively simple virtual environments involves cognitive processes similar to those recruited during real world wayfinding. In a more realistic wayfinding task, based in a VR simulation of a small town, Spiers et al. (2001) also found patterns of impairment in people with ABI consistent with deficits exhibited in real world wayfinding (as described in Chapter 4).

Evidence has also been provided for the recruitment of the same cortical regions for real and virtual wayfinding. Maguire et al. (1997), for example, identified, via fMRI, activation of the posterior hippocampal cortex in participants finding their way around a virtual town. This brain region has been identified as being involved in the representation of large-scale space, and its involvement in real world wayfinding has been implicated by numerous lesion, imaging, and animal studies (see Burgess et al., 1999, Eds, for a review).

In sum, there is an abundance of indirect evidence for the equivalence of virtual and real world wayfinding, in the form of transfer of learning from virtual to real environments,

similar patterns of performance observed in real and virtual wayfinding environments, recruitment of common cortical regions for virtual and real wayfinding tasks, and persistence of real world wayfinding deficits in virtual worlds. However, one type of evidence that is lacking is the simple demonstration of equivalent performance in a real and virtual version of the *same task* in the *same individuals*. This type of evidence has been provided in a study of kitchen tasks in people with ABI by Zhang et al. (2003), in which participants were assessed on their performance in a real and virtual meal preparation task. They found a good correlation between scores on the real and virtual version of the task, demonstrating direct equivalence between real and virtual performance (Zhang et al., 2003).

While the absence of reports in the wayfinding literature of any such simple comparison of performance by the same individuals in a real and virtual version of the same task is somewhat surprising, it can perhaps be explained by the large amount of evidence for equivalence in other forms, such as plentiful evidence for the existence of transfer from virtual to real environments (Farrell et al., 2003). The fact that a simple comparison of performance in a real and virtual task has little practical utility may also explain the dearth of such studies. However, the present series of studies sought to use a virtual town as a stand-alone environment in which to study route learning, so it was particularly important to have strong evidence that the virtual environment was a good *substitute* for a real world environment, not simply a good training environment. The present study, therefore, reports a direct comparison of individuals' performance in the VR town to be used for the series of studies reported in this thesis and their performance in a real-world route of similar length and complexity through a similar type of town.

Furthermore, regardless of whether there is existing evidence for the direct equivalence of route learning performance in real and virtual environments, it would still be important to determine the validity of the specific virtual environment used in the present studies. Virtual environments vary greatly in their features, with environment used in the present study, for example, being dramatically larger in scale and having greater complexity than the virtual environment used by Spiers et al. (2001). Therefore, it cannot be assumed that good ecological validity of previous virtual environments automatically confirms the reliability of any novel virtual environment as a substitute for researching real world wayfinding.

A majority of studies looking at relationships and / or transfer between real and virtual environments have used real world environments and actual virtual simulations of those environments (e.g. Farrell et al., 2003; Stanton et al., 1998, 2000). Because the virtual environment to be employed in the studies reported in this thesis is based upon a town in France, rendered in VR as part of a commercial videogame, it was not logistically possible to use this approach. Instead, the aim was to compare real world route learning ability in general with virtual route learning in our French town. Although this approach reduced the similarity between the virtual and real world routes, potentially reducing the likelihood of finding equivalent performance, it was reasoned that under these conditions reliable correlations between performance on the two routes would be particularly strong evidence that testing within the virtual town provides a good measure of a person's general route learning ability. Furthermore, the software used to create direct simulations real world places in which studies

are carried out (e.g. Brooks et al., 1999), was no longer available at commencement of the present study.

Strategies used are an important variable to consider when examining route learning in any context, as there can be considerable individual differences in the use of strategies (Lawton, 1994; Lawton & Kallai, 2002), and the strategies used can influence performance (Cornell et al., 2003; Kato & Takeuchi, 2003). In order to allow for a thorough comparison of route learning in the real and virtual environments, therefore, checklists asking participants to rate the extent to which they used 7 main wayfinding strategies (described in Chapter 2) when memorising the route within each environment were also administered as part of the study.

5.2 Method

5.2.1 Design

A repeated-measures, within participants design was employed. All participants learned a route through a VR town, and a route through a real world town. The order of conditions was counterbalanced to control for potential practice or fatigue effects. The independent variable was the route (i.e. real versus virtual), and the dependent variable was number of errors made on attempting to recall the route.

5.2.2 Participants

Participants were a convenience sample of 14 neurologically healthy volunteers, 8 males and 6 females, aged between 18 and 54 years, with a mean age of 23.1 years (S.D. = 9.21). Participants were recruited through word of mouth and through the university research participation scheme. All participants received an information leaflet explaining the the study (see appendix E), and gave informed consent (see appendix F for a copy of the consent form).

5.2.3 Apparatus and materials

Two routes were selected, one through the VR town, the other through the real world area of Birmingham. The routes each contained a total of 15 turns, which broke down into equivalent percentages of 'left', 'right' and 'straight ahead' choices, and equivalent percentages of two- and three- choice point junctions. The routes were also designed to take a similar length of time. The average time taken to complete the real world route was 5 minutes, and the average time taken to complete the VR route was 4 minutes and 50 seconds. It also took a similar

amount of time to return to the start-point of the real world route (4 minutes) and the VR route

(3 minutes 30). The two routes are shown below in figures 5 and 6.
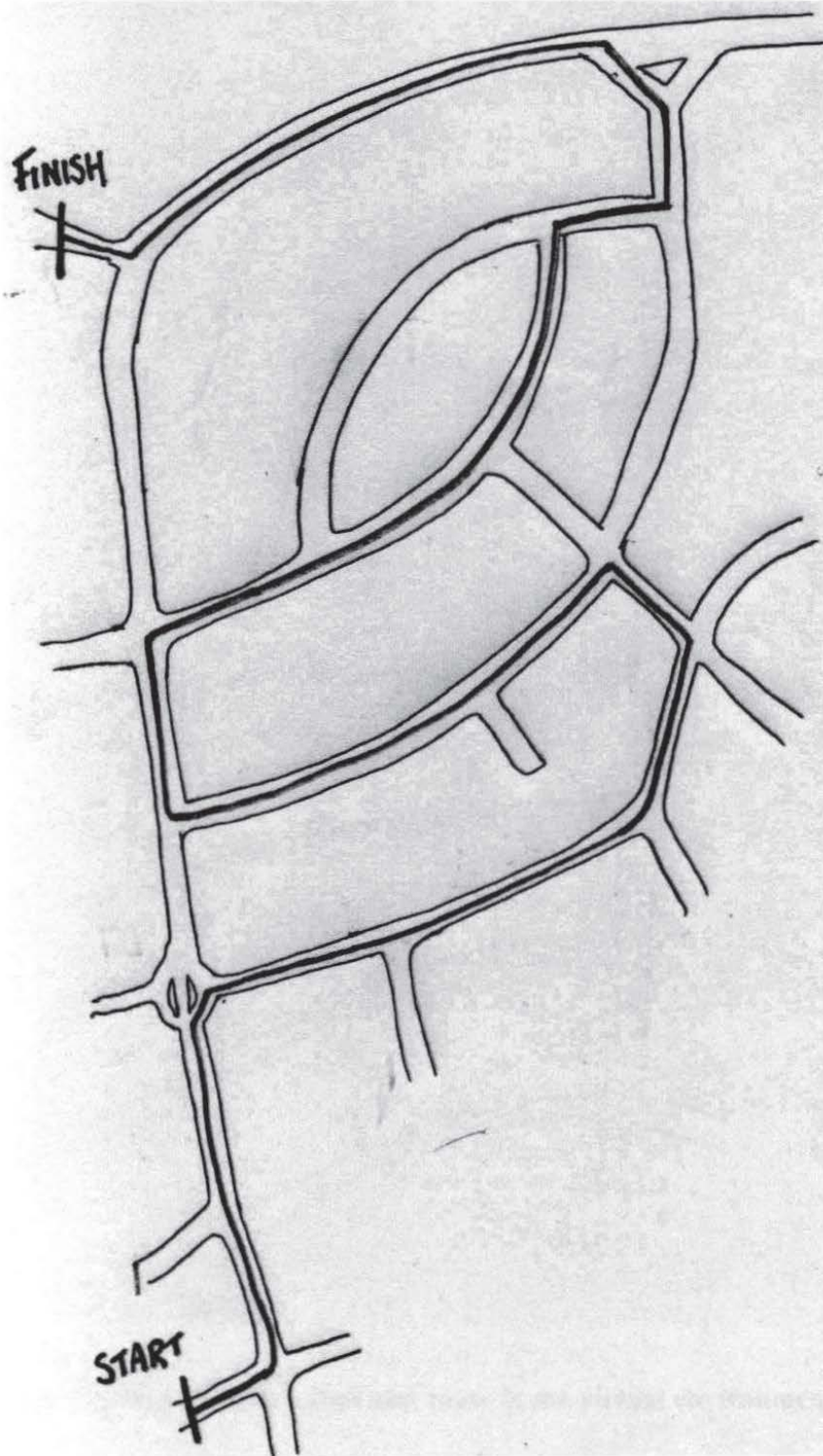
Figure 5: **Map of road layout and route in the real-world environment**
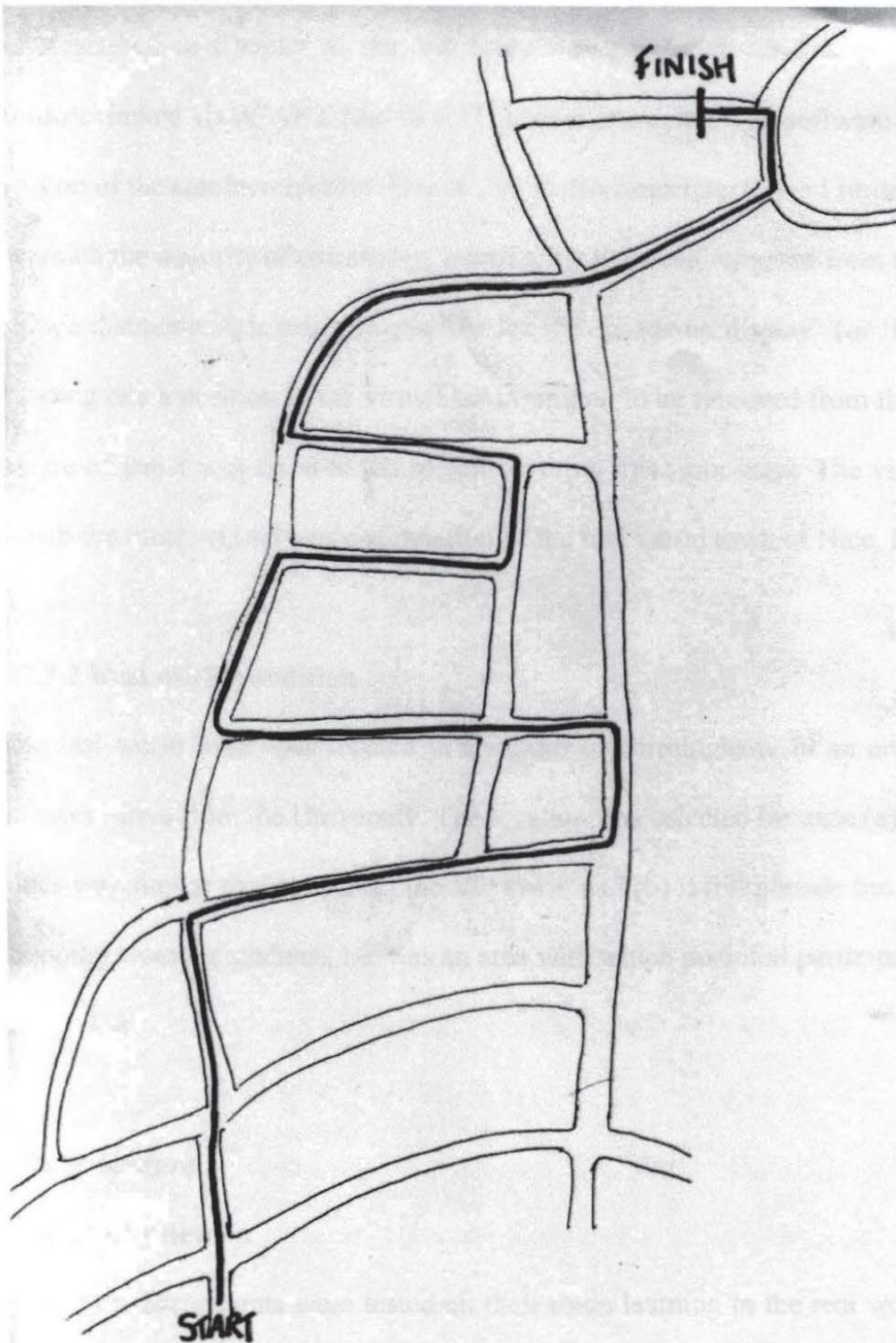
Figure 6 Map of road layout and route in the virtual environment

5.2.3.1 VR condition

As described in Chapter 4, the VR route was presented via a Sony Playstation 2 games console, linked via SCART lead to a 21" colour television. The software used was a modified version of the commercial title 'Driv3r', by Reflections Interactive Limited, an ATARI studio, in which the majority of extraneous information had been removed from the screen in order to reduce distractions. It was not possible for the 'heads-up display' (or 'HUD'), a small map charting one's position in the virtual environment, to be removed from the display, so a small square of paper was fixed to the screen covering this from view. The virtual environment in which the route was set was a simulation of the real world town of Nice, France.

5.2.3.2 Real world condition

The real world route was located in a suburb of Birmingham, in an area approximately 15 minutes' drive from the University. The location was selected because (a) the configuration of roads was similar to that seen in the VR town, and (b) it fell outside the popular residential / shopping areas for students, i.e. was an area with which potential participants were unlikely to be familiar.

5.2.4 Procedure

5.2.4.1 Overview

Half of the participants were tested on their route learning in the real world first, then in the virtual environment. The other half received the opposite order of conditions. In both conditions participants were taken to the start-point of the route, given their instructions and shown around the route, before being returned to the start-point and asked to attempt to call

out directions to the experimenter as she proceeded around the same route for a second time. One point was awarded for each correct instruction provided at least five seconds in advance of the relevant junction by participants, with a maximum possible score of 15 points. After participants completed this test trial, they were asked to fill in a questionnaire (reproduced in appendix A, and discussed in more detail in the following chapter) rating the degree to which they had employed a variety of common wayfinding strategies during to help them perform the task.

5.2.4.2 Virtual reality condition

Participants were seated at approximately arms'-length from the television screen, on which the VR route was pre-loaded at the beginning of the route to be learned. As a precaution, they were firstly told the name of the computer programme being used, and asked whether they had ever used it before. Provided they were not familiar with the programme, they were then asked to watch as the experimenter drove them along a route through the town, imagining that they were actually traveling through the virtual environment. They were told that, after they had seen the whole route, they would be returned to the start and asked to call out directions to the experimenter. They were asked to call out directions at least five seconds before arriving at a junction, to keep the procedure equivalent to that used in the real world where timely instructions were required to allow the driver to indicate before reaching a junction. Participants were asked to call out directions even when the correct choice at a junction was to continue straight ahead. A recap of the instructions was given just prior to commencing the task, and prior to the test trial. Full instructions are reproduced in Appendix C.

On the test trial, if participants attempted to call out a list of several turns in advance (e.g. 'second left, straight ahead and then third right') they were not informed as to whether their instructions were correct, and asked to repeat the appropriate instructions on approach to each individual turn. This was implemented to ensure all participants were required to hold information in memory for an equivalent length of time, rather than unburdening information early on in the test trial.

5.2.4.3 Real world condition

Participants were driven to the beginning of the real world route, approximately 15 minutes away from the University. They were then told to watch as the experimenter drove around a route, and informed that they would then be returned to the start and asked to direct the experimenter around the route. As with the VR condition, participants were asked to call out directions at all junctions, even where the correct choice was to continue straight ahead, and they were asked to call out at least 5 seconds before the junction. Again, participants were asked to repeat directions at each junction if they attempted to provide a string of directions all at once. A recap of the instructions was, again, given prior to starting the learning trial and test trial. Full instructions are reproduced in Appendix C. Participants were informed that their responses would be recorded on a tape-recorder, for later scoring.

5.3 Results

5.3.1 Route learning performance

The mean number of errors made in the virtual environment was 2.57 (S.D. = 1.01), and the number made in the real world was 2.43 (S.D. = 1.55). Paired-samples t-test revealed that there was no significant difference between the two conditions, (t = -.56, df =13, p = .58); in fact, there was a highly significant correlation between them (r=.81, n=14, p<0.0005).

5.3.2 Strategy Use

Correlations between frequency of use of strategies in the real and virtual environments are shown in table 1 below. Spearman's correlations are used because ratings are on a Likert-type scale, for which nonparametric tests are deemed most appropriate (Clason & Dormody, 1994).

Table 1: Correlations between use of strategies in real and virtual route learning tasks.

Strategy	Spearman's correlations between real and virtual environment frequency of use ratings (n = 14, 2-tailed)	
	rho	P
Creating a cognitive bird's-eye map	.88	<0.0005
Using landmarks	.58	0.03
Guessing	.53	0.05
Use of instinct	.54	0.05
Using cardinal reference points	.53	0.05
Use of dead reckoning	.45	0.11
Use of tall, distant buildings	.50	0.07
Memorization of turn sequences	.37	0.19
Use of 'look-back' strategy	-.08	0.80

The extent to which people rely upon creation of a cognitive map, use of landmarks, guessing, and instinct are all correlated across the real and virtual environments. Correlations between virtual and real world use of cardinal reference points and tall distant buildings as landmarks narrowly miss significance. There was no significant correlation between real and virtual tasks in the reliance upon learning sequences of left and right turns, use of dead reckoning and use of the lookback strategy. However paired-samples t-tests showed that there were no significant differences between the extents to which any of the strategies were employed in the real versus virtual environment. Table 2 gives the means and standard deviations for each strategy's frequency of use rating in the real and virtual environment, with the t-test statistics from the paired samples comparisons.

Table 2: Mean frequency of use ratings for strategies in real and virtual environments.

Strategy	Mean frequency of use rating in real world task	Mean frequency of use rating in VR task	t-test comparing means (df = 13)
Memorisation of turn sequences	3.93 (S.D. 0.98)	3.93 (S.D. = 0.73)	t = 0.00, p = 1.00
Guessing	1.64 (S.D. = 0.74)	1.71 (S.D. = 0.83)	t = .366, p = .720
Cognitive mapping	1.64 (S.D. = 1.28)	1.64 (S.D. = 1.34)	t = 0.00, p = 1.00
Use of cardinal reference points	1.29 (S.D. = 0.61)	1.57 (S.D. = 0.94)	t = .108, p = .302
Dead reckoning	3.36 (S.D. = 0.84)	3.21 (S.D. = 1.12)	t = .563, p = .583
Use of landmarks	3.21 (S.D. = 1.37)	3.64 (S.D. = 0.93)	t = 1.58, p = .139
Use of tall, distant landmarks	1.79 (S.D. = 0.80)	2.36 (S.D. = 1.08)	t = 2.10, p = .055
Instinct	2.50 (S.D. = 1.09)	2.14 (S.D. = 0.66)	t = 1.44, p = .174
Use of the 'look-back' technique	1.07 (S.D. = 0.27)	1.07 (S.D. = 0.27)	t = 0.00, p = 1.00

5.4 Discussion

The present study compared route-learning performance in a VR town with performance in a distinct real world route of similar length and configuration. Participants were also asked to rate the extent to which they used seven major wayfinding strategies (plus the extent to which they used instinct and guesswork) to complete each route-learning task. Results showed a strong correlation between the number of errors made in the real and virtual environments, supporting the equivalence of real and VR route learning. The degree to which participants relied upon several of the strategies in the real world environment also correlated with the extent to which they relied upon the same strategies in the virtual town task. While some strategies did not correlate across the two environments, their frequency of use ratings did not differ significantly between the real and virtual tasks.

The finding that route-learning performance in the virtual and real world are well correlated is consistent with previous findings of equivalence between real and VR environments in general (e.g. Rose et al., 2000), and in route learning scenarios in particular (e.g. Farrell et al., 2003; Ruddle, Payne & Jones, 1997; Stanton et al., 2000). Whereas previous studies have demonstrated equivalence of real and virtual route learning through findings of similar patterns of spatial knowledge acquisition (e.g. Ruddle et al., 1997) and impairment (e.g. Skelton et al., 2000) in real and virtual tasks, and in transfer of learning from virtual simulations of an environment to its real world counterpart (e.g. Darken & Banker, 1998), the present study demonstrates equivalence between performance on a route learning task in a virtual town generated by videogame software and a real world route learning task in a

completely different town. The present study, therefore, demonstrates that general route learning ability can be assessed reliably in a VR town, and that performance on a generic route in a virtual environment is indicative of real world route learning aptitude.

The finding of correlations between the real and virtual route learning task in the degree to which many of the listed strategies were employed also strongly supports the ecological validity of VR environments for studying route learning, demonstrating that people rely on similar techniques to memorize a real and a virtual route.

The strategies that just failed to correlate significantly across the two environments were the use of tall, distant buildings as landmarks and the use of cardinal reference points. There were also no significant correlations between use of the look-back strategy, use of dead reckoning, and the technique of memorization of lefts and rights. Although there were, as mentioned above, no significant *differences* between the use of these strategies in the real and virtual tasks, there are a few possible explanations for the lack of outright correlation. In general, it is possible that the small sample size simply resulted in poor power of the statistical tests to detect correlations, particularly for the techniques that are relatively scarcely used by participants resulting in a very small amount of variance, such as the look-back strategy.

More specifically, there may be reasons particular to the strategies that did not correlate across the two tasks. For example, the virtual route contained slightly more tall buildings than the real world route, which may be responsible for the slightly greater reliance upon the technique of navigating towards tall, distant landmarks in the VR condition. The fact that this

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effect is likely to be attributable to differences between the two routes, rather than intrinsic differences between the real and virtual environment, means that it does not present a serious challenge to the ecological validity of the VR town.

Similarly, cardinal reference points may have been used more frequently (though not significantly so) in the virtual environment simply because of the presence of a coastline at one point in the route. This might have been a cue that helped some people use cardinal directions to a greater extent in the virtual environment than the real environment.

The reason why participants used the look-back strategy less in the virtual world (though not significantly so), is most probably because they could not look behind them in the virtual task without asking the experimenter to move the viewpoint, whereas they were able to glance into the side mirror of the car or turn to look out of the back window at their own discretion during the real world task. Because benefit from the look-back technique has only been demonstrated in route reversal tasks, however, whereas the present series of studies involve learning routes forwards, the restriction upon its use in the virtual environment is not of great concern. Future studies wishing to test route reversal in a virtual task, however, should consider the possibility that an effective technique in route reversal may be somewhat compromised in VR.

The use of dead reckoning across the real and virtual environments may have also failed to correlate because of less opportunity to use the technique in the virtual town. Although successful dead reckoning has been demonstrated in virtual environments (Riecke, VanVeen & Bülthoff, 2002), some researchers do argue that sensorimotor and kinaesthetic feedback is

important for this technique (Berthoz & Viaud-Delmon, 1999). It is possible that the lack of physical information available to inform dead reckoning in the virtual environment contributed to the lack of significant correlation between usage in the real and virtual task.

It is more difficult to suggest a reason for the lack of correlation between memorization of sequences of lefts and right turns in the real and virtual environments. The routes took an equivalent length of time to complete, so a difference in working memory demands of using this strategy across the two environments is unlikely to be the cause. The mean ratings for this strategy for the two conditions were identical, suggesting that there is no systematic difference in the extent to which people call upon this strategy in the real and virtual world. Because the memorization of left and right turn sequences has not been found to be a particularly useful technique in previous studies (e.g. Kato & Takeuchi, 2003), however, it is not a strategy that will be actively encouraged in the studies reported later. In light of this, and because no significant difference was found between the use of this strategy in real and virtual task, the lack of a significant correlation does not cause great concern.

On balance, the virtual environment assessed in the present study appears to have excellent equivalence with the real world as an arena for route learning. Not only does route-learning performance in the virtual town reflect real world route learning performance; there are also good correlations between the extent to which participants employ many common wayfinding strategies when learning a route in the virtual and real world environments. Nor do there appear to be any pronounced differences in the extent to which any of the major wayfinding strategies are used in the real and virtual environments.

CHAPTER SIX

PILOT STUDY TWO: INDIVIDUAL DIFFERENCES IN ROUTE LEARNING STRATEGIES, AND THEIR RELATIONSHIP WITH PERFORMANCE, CONFIDENCE AND EXPERIENCE

6.1 Introduction

Route learning is achievable by means of a wide range of strategies. A number of individual differences have been demonstrated in the strategies or types of strategies favored in route learning (and more generally, in wayfinding) tasks[1]. Furthermore, there is evidence to suggest that some strategies are more effective than others, although the performance measures used to assess effectiveness of learning can influence the apparent value of a given strategy. In order to single out the most effective naturalistic strategies to apply to route learning in people with ABI, the present study sought to assess the relative effectiveness of a number of different strategies in various ways. The most obvious measure of a strategy's effectiveness is the relationship between performance on wayfinding tasks and use of the strategy. The value of a strategy can also be assessed in terms how confident in their wayfinding ability people who rely upon it feel. It may also be useful to consider the type of people who use a given strategy, as there may potentially be illuminating strategy preference differences between males and females, older and younger people, and experienced wayfinders. In a bid to identify the best possible strategies to employ in study number 4, where naturalistic strategies were to be combined with errorless learning techniques, the present study compared the relative utility of

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[1] See Chapter 2 for an explanation of the difference between 'wayfinding' and 'route learning'

the main wayfinding strategies. This was done by assessing how use of each strategy relates to route learning performance, wayfinding confidence and wayfinding experience.

While there are a number of strategies involving the use of external aids such as maps or directions (e.g. Lawton, 1994), we focus here upon strategies that can be used for independent or unassisted wayfinding, as described below. Specifically, findings from the literature concerning the relative effectiveness of the seven main route learning strategies introduced in Chapter 2 (section 2.2) are summarised below.

Cardinal references have been found to be used more by participants with a self-reported good sense of direction than by those who described their direction sense as poor (Kato & Takeuchi, 2003), and from qualitative 'think aloud' data from a route learning task participants with a good sense of direction were characterized by 'full or partial reliance on the absolute reference system of cardinal direction' (Kato & Takeuchi, 2003, p185). Self-reported sense of direction appears to be a valid measure of objective ability, with (in a similar study) people reporting good sense of direction making fewer route-recall errors than those claiming to have a poor sense of direction (Cornell et al., 2003). It is possible, therefore, that use of cardinal references is a relatively effective strategy (although the direction of causality between strategy use and proficiency cannot be proven).

The memorization of turn sequences appears to be a mediocre strategy, used to an equal extent by participants reporting poor and good sense of direction, and being neither the least nor most used strategy by either group (Kato & Takeuchi, 2003). It was used significantly less

than landmarks by good wayfinders, however, and significantly more than the cardinal references by poor wayfinders, which could very loosely be taken to suggest that it is a relatively poor strategy. The qualitative 'think aloud' data also showed that this strategy was used particularly heavily (with poor results) by two of the participants in the 'poor sense of direction' category (Kato & Takeuchi, 2003). Furthermore, it seems intuitively likely that memorization of turns (presuming this relies upon verbal rehearsal of the turn sequence), will be a poor strategy for any route exceeding a person's working memory capacity.

Landmark use is one of the most widely employed wayfinding strategies (e.g. Lawton, 1994), and people reporting a good sense of direction rely upon this technique significantly more than any other (Kato & Takeuchi, 2003). Because only three strategies made up Kato & Takeuchi's (2003) checklist it is possible that additional, omitted strategies would have been equally characteristic of people with a good sense of direction, but a preference for landmarks in these participants is also expressed in the 'think-aloud' data, when participants were free to report use of any strategy (Kato & Takeuchi, 2003).

Cornell et al. (2003) found, on a route-learning task, that people with a self-reported 'good sense of direction' did not simply recall more landmarks, but recalled more landmarks associated with route decision points, than those with poor sense of direction. This suggests use of landmarks, particularly those in key positions along a route, is a strategy used by both efficient and confident wayfinders. The fact that knowing which landmarks to use for greatest effect is related to wayfinding performance is also promising in terms of the patient study

introduced in Chapter 8, as it may indicate that even people who already use landmarks may benefit from instruction to use landmarks located at route decision points.

Cornell et al. (2003) found that significantly more people with a good sense of direction than those with a poor sense of direction used global landmarks, 'to fix their positions within a large-scale spatial framework' (Cornell et al., 2003, p 420). Jacobs et al. (1997) compared the use of proximal and distal landmark use in an invisible target search task in a simple virtual environment. They found that when both proximal landmarks (in the form of objects located within a circular arena) and distal landmarks (in the form of the colours and patterns of walls of a square room around the arena) were available, participants relied preferentially upon distal landmarks (Jacobs et al., 1997). However, in a more realistic virtual environment, simulating a small network of streets and buildings, Steck and Mallot (1997) found that participants relied upon both local landmarks (such as buildings or other objects located at junctions) and global landmarks (such as hills or a radio tower in the distance) to guide navigation. They also found that individuals varied in their preferred type of landmark, but were able to use either type when the alternative was unavailable. These studies do not specifically address the question of which type of landmark use is most effective as a strategy, but do demonstrate that both types of landmark can be equally useful, and that the particular features of a given environment or decision point will affect the appropriateness of global versus distal cues. Again, this information is potentially important for the study described in Chapter 8, as it suggests that it may by useful to promote the use of both distal and proximal landmarks if a technique based around landmarks is implemented.

Although relatively obscure, the 'look-back' strategy can improve performance on a route reversal task when participants are instructed in how to use it (Heth et al., 2002). Whether this strategy would have any benefit for recall of a non-reversed route, as is required in the routes studied in the present series of experiments, however, is unclear.

Dead reckoning (defined in Chapter two) has been highlighted as a relatively ineffective strategy, that 'everyone knows how to use (even if poorly)', and which 'is therefore the fall-back technique for individuals who have not yet developed skills for using landmarks and terrain features' (Darken & Goerger, 1999, p. 162). They base this comment on the observation that dead reckoning is over used by inexperienced orienteers, relative to intermediate and expert personnel, but this could be specific to the open outdoor environment used in their study. In a different environment, however, Cornell et al. (2003) also found that self-reported sense of direction did not predict performance on tasks involving cognitive processes directly related to the process of dead reckoning, from which they extrapolate that the technique is not associated with particularly high wayfinding ability. Cornell et al. suggest that the effectiveness of dead reckoning as a strategy may be situation dependent, and 'may be especially important for reconstructing routes when distant cues for bearing are unavailable, such as in corridors between buildings' (Cornell et al., 2003, p408), so it is possible that dead reckoning would be associated with good wayfinding in an indoor scenario.

Overall there is mixed support for the effectiveness of dead reckoning. As it may be particularly suited to indoor routes, and is, intuitively, less straightforward to train a person in than a more easily explained (and widely-known) technique such as landmark use, it seems at

this point that dead reckoning may not be a particularly suitable technique to be used by the study of outdoor route learning described in Chapter 8.

Cognitive mapping is a technique that has been suggested to be characteristic of the most developed wayfinders (Prestopnik & Roskos-Ewoldsen, 2000; Siegel & White, 1975). It might, intuitively, be expected to be a particularly effective wayfinding technique: For example, a mental representation of the configuration of an environment could potentially facilitate the calculation of short-cuts, direct distances between points, and relative positions of landmarks within an area (e.g. Prestopnik & Roskos-Ewoldsen, 2000), and may also assist a person in the recall of routes between places represented in their 'mental map'. Much of the literature on use of cognitive mapping employs performance measures (rather than questionnaire data) to assess the presence and / or quality of the cognitive map a person may have developed. For example, people might be asked to make judgments about Euclidean directions and distances between locations (e.g. Cornell et al., 2003), or to produce an actual sketch map of a given environment (e.g. Billinghurst & Weghorst, 1995).

Billinghurst and Weghorst (1995) found correlations between cognitive mapping (as measured by sketch-maps) and self-reported degree of orientation and knowledge of positioning of things within a virtual world, supporting the idea that cognitive mapping is a particularly effective technique. In Cornell et al.'s (2003) study participants with a good sense of direction were particularly likely to refer to configurational knowledge of a route, indicating that they had formed some manner of cognitive map, and these participants were able to negotiate a shortcut more rapidly and more efficiently than those who failed to use

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configurational knowledge. Lawton & Kallai (2002) found that use of an orientation strategy (i.e. cognitive mapping) correlated with the amount of wayfinding experience people reported, and also correlated inversely with wayfinding anxiety, suggesting that cognitive mapping is characteristic of both practised and confident wayfinders.

Whilst some researchers insist that formation of a cognitive map is the pinnacle of wayfinding knowledge, however (e.g. Prestopnik & Roskos-Ewoldsen, 2000), Aginsky et al. (1997) found that there was no difference in route recall in a virtual environment between those who developed a comprehensive cognitive map (evidenced by sketch maps produced) and those who failed to develop one. They propound that creating a cognitive map of an environment is only one way of approaching the wayfinding problem, and that other strategies can be equally effective. It is likely that for cognitive mapping, along with all of the aforementioned strategies, the nature of the wayfinding task influences the effectiveness. In short-cut calculations, for example, the benefits of possessing a cognitive map are clear, while in a straightforward route recall task (such as is used by the present series of studies), or landmark recognition test, it may be less likely that cognitive mapping will confer any advantage.

In addition to all of the aforementioned strategies, sometimes people report relying upon instinct when making wayfinding decisions. In a real-world short-cut calculation task, the method most commonly cited by participants in Cornell et al.'s (2003) study was use of intuition. The fact that participants referred to the concept of intuition, rather than 'guesswork', along with the fact that intuition was not reported more by poorer wayfinders, suggests that the process was not random, but rather guided by knowledge that was difficult to

verbalize. Guessing, on the other hand, is also a strategy (or 'non-strategy') that is probably employed at times by individuals who are particularly inefficient. It may be important to allow participants to report the use not only of the strategies described above, but also the use of guessing and intuition, in order to provide a comprehensive picture of their strategy use.

In summary, the literature suggests that cognitive maps, cardinal directions and landmarks (both local and global) are all used by people who report having a good sense of direction or high wayfinding confidence, or demonstrate good wayfinding performance in objective tests. Looking back periodically whilst navigating a route is effective in improving ability to reverse a route (i.e. return from the destination to the startpoint), but its applicability to other types of wayfinding task has not been measured. Simple turn sequence memorisation has not been identified as an especially good, nor an especially poor technique, and has received little attention in the literature, possibly because it is rarely used in isolation. Intuitively, though, it is a poor strategy for routes with sequences of turns exceeding working memory capacity. Dead reckoning has generally been dismissed as a poor backup strategy, used by those not capable of effectively using more effective strategies (Darken & Goerger, 1999). People may also rely on guesswork or the use of intuition when learning a route.

Whilst strategies based around landmarks, cognitive maps and cardinal directions appear to be the most effective, it is difficult to incorporate all of the findings to see exactly which strategies are the best. Some studies have assessed relationships between spontaneous self-report of strategy use and performance on wayfinding tasks (Cornell et al., 2003; Kato & Takeuchi, 2003), while others have asked participants to rate their reliance upon a handful or

predefined strategies (Kato & Takeuchi, 2003), and examined how these ratings relate to performance and self-rated sense of direction. Still other studies have attempted to induce reliance upon a given strategy in order to assess its effectiveness (Heth et al., 2002). The wayfinding scenarios and performance measures used in studies of strategy use also vary widely, as do the measures of wayfinding confidence or scales of self-reported proficiency.

The present study, therefore, sought to assess, within one group of participants, how use of each of the main wayfinding strategies described above was related to the subjective measure of self-reported wayfinding confidence and the objective measure of performance on a realistic VR route-learning task. This was an important objective in order to allow for informed selection of the most promising techniques to employ alongside errorless learning in experiment 4, which examines the effectiveness of adding naturalistic route learning strategies to errorless methods to improve route learning in people with ABI.

Measures of the frequency with which a person encounters novel environments were also included, as there has been some evidence that more experienced wayfinders may favour or excel in the use of techniques that novices find difficult to master (Darken et al., 1998). Amount of wayfinding experience in childhood has also been shown to correlate with the use of wayfinding techniques based on configurational knowledge and with wayfinding confidence (Lawton & Kallai, 2002). In order to assess experience in the present study, people were asked to estimate the number of times over the previous twelve months they had taken a trip lasting two days or more to an unfamiliar town, and the frequency with which they visited novel locations on day trips. Measures of current predominance of wayfinding experiences

were selected to allow an investigation of the immediate relationships between participants' wayfinding behaviour and their strategy use, confidence and efficiency (rather than the way in which their wayfinding may have developed across the course of the life span – a question which is beyond the scope of the present study).

Performance on a VR route-learning task was used as a measure of performance, to allow for an investigation into the relationships between strategy use and wayfinding effectiveness. Route learning was selected because (a) it is an ecologically valid wayfinding task that has been relatively under used in favour of configurational knowledge tests, which may be biased in favour of people who use cognitive mapping, (b) it is relatively straightforward to assess, and (c) the patient studies, for which this study serves as a pilot, are interested particularly in route learning, for reasons discussed in chapters two and three.

Confidence was selected as the self-report measure (rather than ratings of 'sense of direction'). Whilst asking participants to rate their sense of direction requests a relatively straightforward assessment of ability, asking for confidence ratings prompts participants to describe their level of comfort with performing a given task in a given scenario. As the route learning task serves as an objective measure of ability, it was considered more valuable to use the self-report measure to assess the more subjective construct of confidence. Confidence is important because a lack of confidence in one's ability to remember a route, or get to a desired destination can be unpleasant and may lead to anxiety; and it is possible that confidence impacts upon actual the likelihood a person will attempt various tasks involving wayfinding (Lawton & Kallai, 2002).

In order to have a particularly sensitive measure of confidence, a checklist asking people to rate their confidence in several possible wayfinding scenarios was devised. Because different wayfinding scenarios demand quite diverse cognitive skills, it is possible that some individuals are very good in some and relatively poor in other situations requiring wayfinding. It is also likely that this is related to the strategies people employ. For example, as mentioned above, dead reckoning is an effective strategy in enclosed, relatively constricted environments such as corridors (Cornell et al., 2003), but may be a relatively poor technique to rely upon in an outdoor orienteering exercise (Darken & Goerger, 1999), which might well be reflected in the confidence a person relying largely upon dead reckoning has in their ability to find their way in each scenario. Five scenarios were selected to represent the main types of situation in which a person may be required to call upon their wayfinding abilities, and the descriptions of these scenarios are reproduced in Appendix B.

It was considered likely that some gender differences would emerge, certainly in strategy preferences and possibly also in performance, based on findings of male superiority in a many wayfinding studies and of gender differences in strategy use (Collucia & Louse, 2004), as discussed in Chapter Two. Because tasks involving route learning are less prone to producing a male superiority effect than measures of configurational knowledge (Postma et al., 2004), however, it was also considered possible that both sexes would perform equally well.

In terms of strategies, as females refer to left and right turns more than males do when giving directions (McFadden, Elias & Saucier 2003), and report, on questionnaires, greater reliance

upon landmarks but less reliance upon cardinal references, than males (e.g. Lawton, 1994), it was expected that strategy preference differences between males and females, if seen, would reflect these biases. The presence or absence of gender effects may have implications for the selection of participants for Experiment 4, where people with ABI are encouraged to use specific strategies. If gender effects are marked it may be necessary to use a single sex sample, or recruit similar numbers of males and females and potentially analyze some results separately.

Age effects in wayfinding have also been demonstrated (Wilkniss et al., 1997), and different patterns of neural activity during a VR wayfinding task have been observed for young and older adults, supporting the reliability of the effect (Moffat et al., 2006). However, many of the studies demonstrating these effects examined differences between groups of young and elderly participants with a difference of 40 years or more between their mean ages (e.g. Moffat et al., 2006; Wilkniss et al., 1997), so it is difficult to deduce whether a gradual age related decline occurs, or in what age range performance begins to decline.

In summary, in order to inform the choice of wayfinding strategies for experiment 4 (the assessment of naturalistic wayfinding strategy use in conjunction with errorless learning for people with brain injury) the present study assessed the value of the main wayfinding techniques reported in the literature. This was done by looking at the relationships between the frequency with which participants reported relying upon each of the strategies and their objective wayfinding performance, their self-reported wayfinding confidence and their typical amount of wayfinding experience. Gender and age were also examined, although they were

peripheral to the main purpose of the study. It was hypothesised that the extent to which people relied upon the particularly effective strategies of landmark use, cognitive mapping, and use of cardinal reference points would be reflected in good performance on the route learning task and high ratings of wayfinding confidence. No predictions were made about how the other strategies would relate to confidence and performance. A tendency for males to use cardinal directions more and landmarks less than females was also expected, and possibly an effect of gender on performance, with males making fewer errors than females. A tentative prediction of an inverse correlation between age and performance was also made, although because this was not a major research question in the present study the sample was not specifically chosen to span a cross section of ages.

6.2 Method

6.2.1 Participants

A total of 29 participants completed the study; 18 females and 11 males, aged between 17 and 59 years, with a mean age of 24.3 years (S.D. = 10.45). Participants were recruited through word of mouth and through the University research participation scheme in exchange for research credits. All participants received an information leaflet explaining the study (see Appendix E), and gave informed consent (see Appendix F for a copy of the consent form).

6.2.2 Apparatus and materials

The apparatus was exactly as described in the previous chapter (see section 5.2.3).

The route, which passed through 14 choice points or junctions (giving 14 opportunities to make errors) in the virtual simulation of the French Town of Nice, is shown in Appendix D; route C).

A questionnaire scale asking participants to rate the extent to which they used the seven main wayfinding strategies described in the introduction (proximal landmark use; distal landmark use; dead reckoning; cognitive mapping; use of cardinal reference points; use of a 'look-back' technique; and memorisation of turn sequences), plus 'guessing' and use of 'instinct'. Respondents could rate the extent to which they relied on each item on a 5-point Likert scale with the titles from points 1 to 5 being; 'not at all', 'a little'; 'a moderate amount'; 'a lot'; and

'almost totally'. The scale is reproduced in full in Appendix A. The internal reliability of the nine-item scale is .527, and when guessing is removed from the scale it improves to .597.

A confidence strategy scale was also administered to assess participants' confidence in their ability to find their way in several common wayfinding situations, such returning to a car park after exploring a new town. The full six-item confidence scale is reproduced in Appendix B. Crohnbach's alpha for the scale is .597.

6.2.3 Procedure

At least 24 hours prior to arriving for the study, participants completed the confidence scale via email and returned it to the experimenter. This was in order to avoid any potential influence that rating one's confidence might have on route learning, were it to be carried out immediately prior to a route learning task, and to avoid any biases that might result from task performance, were it to be carried out post-task.

Upon arrival for the main route-learning study, participants were seated at arms' length from the television screen, and the VR town was introduced to them. The use of the control pad was then demonstrated, and participants were given five minutes to practice moving around a virtual simulation using the same software in a location not used during the route learning task. After five minutes, participants rated their confidence in using the control pad on a 5-point Likert scale, ranging from 'not at all confident' through to 'completely confident'. They were then asked to perform a series of movements (reflecting the movements required for the main task) in the virtual town, prompted by the experimenter, and this exercise was timed. If

participants either (a) rated their confidence in using the control pad as three or less (i.e. expressed that they were 'somewhat confident', had 'a little confidence', or had 'no confidence') (b) failed to execute any of the manoeuvres, or (c) were unable to complete the sequence of manoeuvres in under one minute, they were given an additional two minutes to practice using the controls, before being tested again on confidence and ability. If they still did not meet any of the aforementioned criteria, they were given two more minutes of practice time, before being tested for a final time on their use of the control pad. After this point participants proceeded to the main experiment (all participants were able to reach criterion by this point).

In the route-learning task, directions were called out to participants as they approached each junction, and they followed the route they were directed along. Upon reaching the end of the route, the experimenter returned the participant to the route start-point. Participants were then asked to attempt to complete the same route from memory three consecutive times, without directions (even if they successfully completed the route before the third attempt). They were informed that, were they to take a wrong turn, they would be corrected after five seconds of moving in the wrong direction, so that they would have this amount of time to correct their own path spontaneously. The main outcome measure was the number of incorrect turns taken, and the number of self-corrected errors (i.e. wrong turnings that participants spontaneously recovered from within five seconds) was also recorded as a supplementary measure of performance. After the final route learning trial, participants were asked to complete the strategy questionnaire introduced above.

6.3 Results

6.3.1 Questionnaire data

Tables 3 shows the mean frequency with which participants reported using each of the wayfinding strategies described in the questionnaire, with five being the maximum rating (equating to the response 'almost totally') and one being the minimum rating (equating to and the response 'not at all'). Landmark use and memorisation of sequences of turns are the most popular strategies, and the least popular is the use of cardinal reference points.

Table 4 summarizes the mean confidence ratings for each of the six wayfinding scenarios, with zero equating to 'not at all confident' and four equating to 'totally confident'. The highest mean confidence rating of 2.44 (which would be between 'somewhat confident' and 'very confident') was given for returning to one's car (or bus stop etc) after shopping or sightseeing in a strange town. The lowest confidence rating was for returning to a place visited once before.

Table 3: Mean frequency of use ratings for each wayfinding strategy (in order of descending popularity)

Strategy	Mean frequency of use rating (SD)		
	Males (n = 11)	Females (n = 16)	Total (n = 27)
Use of landmarks along the route	3.64 (0.51)	3.06 (0.77)	3.30 (0.72)
Memorisation of left and right turns	2.36 (0.81)	2.31 (.70)	2.33 (.73)
Use of tall, distant landmarks	1.70 (1.17)	1.69 (1.30)	1.69 (1.23)
Use of instinct	1.18 (0.98)	1.25 (0.78)	1.22 (0.85)
Use of the 'look-back' strategy	1.36 (1.50)	0.56 (0.89)	0.89 (1.22)
Guessing	0.18 (0.41)	0.94 (0.44)	0.63 (0.57)
Cognitive mapping	0.73 (1.10)	0.13 (0.34)	0.37 (0.79)
Use of cardinal reference points	0.00 (0.00)	0.13 (0.50)	0.07 (0.39)

Table 4: Mean confidence ratings for wayfinding in various scenarios.

Wayfinding scenario	Mean confidence rating (SD)		
	Males (n = 11)	Females (n = 16)	Total (n = 27)
Wayfinding in a car	2.18 (0.75)	1.75 (0.78)	1.93 (0.78)
Returning to car park after exploring a new town	2.73 (0.79)	2.25 (0.86)	2.44 (0.85)
Returning to a place visited once before	2.00 (1.20)	1.38 (0.62)	1.63 (0.88)
Returning to a room in a large building	1.73 (1.10)	2.00 (0.63)	1.89 (0.85)
Using a road map / 'A to Z'	2.64 (1.03)	2.13 (1.26)	2.33 (1.18)
Giving directions in one's home town	2.00 (1.00)	2.50 (0.82)	2.30 (0.91)

6.3.2 Route recall performance

The mean number of errors made by participants overall across the three test trials was 5.44, range 0 to 13 (out of a possible maximum of 42). Spontaneously corrected wrong turns were

very rare, with participants making, on average, fewer than one spontaneous error correction across the entire three trials, so this measure was not used in the analysis.

Table 5 shows the correlations between the extent to which participants reported using each of the strategies and number of incorrect turns taken. The only strategies to correlate significantly with incorrect turns were landmark use and cognitive mapping, which correlated inversely, and guessing, which correlated positively.

Table 5: Correlations between frequency of use of strategies and number of wrong turns taken.

Strategy	Spearman's correlation with number of wrong turns (2-tailed) (n=26)
Cognitive mapping	-.54 (p = 0.00)
Guessing	.52 (p = 0.00)
Use of landmarks along the route	-.46 (p = 0.01)
'Look-back' strategy	-.35 (p = .08)
Memorising left and right turns	.30 (p = .13)
Using cardinal reference points	-.30 (p = 0.12)
Using dead reckoning	-.14 (p = .47)
Using distant buildings as landmarks	-.10 (p = .61)
Instinct	.03 (p = .89)

Because all participants were required to be at least moderately confident with the control pad in order to proceed to the route-learning task, there were, in the end, only three possible ratings on the 5-point Likert scale – 'moderately confident', 'very confident', and 'totally confident.' A correlation was therefore deemed inappropriate, but a oneway ANOVA

revealed a significant effect of participants' self reported confidence using the control pad on number of errors made ($F_{(2,23)}$ = 7.91, p = 0.00). Post-hoc t-tests indicated that the significant difference lay between people who were moderately confident and those who were very confident using the control pad (t = 3.41, d.f. = 15, p = 0.00), and those who were moderately confident and those who were totally confident (t = 3.78, d.f. = 13, p = 0.00). There was no significant difference in the error rates of participants who were very confident and those who were totally confident in control pad use (p>0.05).

Spearman's correlations were also carried out in order to test for relationships between performance on the route learning task and the other demographic details collected, as described in the method, and the results are shown in table 6. The number of hours spent playing computer games per week showed a trend towards correlating inversely with errors made, and the correlation between errors and age just missed significance. Neither measure of wayfinding frequency correlated with performance.

Table 6: Correlations between demographic measures and errors on route learning task.

Measure	Correlations with errors on route-learning task (2-tailed, n = 27).
Age	r = .34 (p = 0.08)
Hours per week of computer game play	r = -.39 (p = .06)
Number of (2 day or longer) trips to new places taken over the last 12 months	r = .03 (p = .87)
Frequency of day-trips to new places	rho* = .01 (p = .97)

*Spearman's rho is used for this correlation because frequency was rated on a Likert-type scale, making nonparametric analysis most appropriate (Clason & Dormody, 1994)

6..3.3 Wayfinding confidence

Confidence in wayfinding in a car was correlated with creation of a mental map (rho = .41, n = 26, p = 0.04, 2-tailed), and memorisation of landmarks (rho = .43, n = 25, p = 0.03, 2-tailed). Confidence returning to a given room in a large building correlated with use of the look-back strategy (rho = -.44, n = 26, p = 0.03, 2-tailed). Confidence wayfinding using a map correlated inversely with using tall, distant buildings as landmarks (rho = -.49, n = 25, p = 0.01).

Self-reported confidence in wayfinding in a car (rho = .48, n = 25, p = 0.01), and returning to a car park (or bus or train stop) (rho = .54, n = 25, p = 0.00) correlated with the number of (2 day or longer) trips to new places a person had taken in the last 12 months. The composite score for confidence, calculated by summing confidence in each of five scenarios, also correlated significantly with number of trips taken (rho = .433, n = 25, p = 0.031). Confidence returning to a place visited once before (r = .61, n = 26, p = 0.00) correlated with the annual frequency of day-trips to new places.

6.3.4 Gender

There was no significant difference between males and females in route recall (t = -1.83, d.f. = 27, p = 0.08, 2-tailed), although the mean errors definitely suggest a male advantage with mean error score for males of 3.81 (S.D. = 3.49) compared with a score of 6.33 (S.D. = 3.66) for females (effect size: d = 0.71).

Males and females differed significantly in their use of guessing (t = -4.34, df = 24, p <0.005, 2-tailed). There was also a gender difference in use of landmarks along the route (t = 2.16, df = 25, p = 0.04, 2-tailed). The gender difference in use of cognitive mapping approached but did not reach significance (t = 1.75, d.f. = 11. 33, p = 0.05, 2-tailed).

Males reported playing significantly more hours of computer games per week than females (mean of 7.43 hours (S.D 5.50) compared with a mean of 1.92 hours) (t = 2.83, df = 13.48, p = 0.03, 2-tailed).

6.4 Discussion

The present study investigated wayfinding strategy use, and how it related to objective measures of route recall in a VR town task, self-report wayfinding confidence measures, and frequency with which participants reported encountering novel wayfinding situations in their everyday life. Gender and age effects were also explored.

The most frequently used strategies were landmark memorization and memorization of turn sequences. However, females guessed more and used landmarks more and males 'tended' to use maps more. Performance on the route-learning task correlated with use of a cognitive mapping strategy and memorisation of landmarks along the route, and correlated inversely with reliance upon guessing. Neither the wayfinding experience nor the wayfinding confidence measures appeared to be related to route recall, but confidence did correlate with amount of wayfinding experience, and there were some relationships between confidence and strategy preferences. Confidence wayfinding in a car correlated with using cognitive mapping and landmark memorisation, while confidence wayfinding indoors correlated with use of the 'look-back' strategy, and confidence wayfinding using a map correlated inversely with using tall, distant buildings as landmarks. Males made fewer errors over all, and reported relying less upon guessing than females. They also reported a higher frequency of computer game play.

The inverse correlation between guessing and performance is largely self-explanatory, suggesting that people who had difficulty recalling the route were forced to rely upon

guessing. It demonstrates that participants had reasonably good insight into their own strategy use (or lack thereof). The fact that the extent to which participants reported using intuition, by contrast, did not correlate with errors demonstrates that people can differentiate between when their responses are unreliable and random from when they are based upon implicit knowledge.

The inverse correlation between landmark use and errors is consistent with previous findings that good wayfinders report paying attention to landmarks (Kato & Takeuchi, 2003). It is somewhat inconsistent with the idea that reliance upon landmarks is the most basic strategy in wayfinding (e.g. Siegel & White, 1975), although this idea relates specifically to the use of landmarks in isolation, whereas high ratings for landmark use in the present study did not necessarily indicate reliance solely upon this technique.

The correlation between performance and use of cognitive mapping is also consistent with previous findings in the literature that good wayfinders use cognitive mapping (Cornell et al., 2003; Kato & Takeuchi, 2003). This relationship emerging on a route recall task is interesting, as this strategy is usually associated with good performance on tasks requiring survey knowledge, such as estimating Euclidean distances and directions between points within an environment (e.g. Mallott et al, 2002), or calculating detours (Cornell et al., 2003). The fact that cognitive mapping is not *necessary* for route recall in the same way that it is required for tasks that demand configurational knowledge, however, does not mean that it cannot be *beneficial* for route recall. Creating a cognitive map appears to have enabled participants in the present study to recall the route more effectively than those who did not use

cognitive mapping. It is also possible, however, that cognitive mapping and good route recall are not directly related, but are simply both attributes of 'good' wayfinders.

The effect of confidence using the control pad upon error rates indicates that, despite the measures taken to familiarize participants with the computer interface, the amount of comfort participants felt when controlling their movement through the town was related to their performance. Increased working memory demands upon participants who were less confident interacting with the virtual town may have interfered with their ability to learn the route; this is consistent with findings that attention-consuming concurrent tasks interfere with route learning ability (Garden et al., 2002).

The trend towards a correlation between age and route recall errors is consistent with previous findings (e.g. Wilkniss et al., 1997). Participants were recruited as a convenience sample and, because age was not a major research question for the present study, were not selected based upon age. Consequently, age was not normally distributed, and the range of ages (17 to 59 years), was smaller than that of studies that have demonstrated age effects (e.g. Moffat et al., 2006; Wilkniss et al., 1997), which could have reduced the probability of finding a significant relationship between age and error rates.

The fact that participants' self-reported confidence in various wayfinding scenarios was not correlated with performance suggests that subjective ratings of confidence may not be as predictive of ability as subjective ratings of 'sense of direction' that have been found to

correlate with performance in previous studies (Cornoldi et al., 2003; Kato & Takeuchi, 2003), consistent with the idea that a confidence measure would provide different information than a measure of ability. Being able to identify strategies that are associated with high wayfinding confidence may be important not only because it simply is more pleasant to feel confident than anxious, but also because people who do not feel confident in their ability to find their way may be less likely to put themselves into situations requiring independent wayfinding. This is not only restrictive, but could also conceivably compound the problem by removing the opportunity for improvement through practice. This theory is supported by findings that some of the confidence measures were actually related to participants' frequency of wayfinding experiences. The number of trips to new places, of two or more days' duration, that participants had taken over the past 12 months correlated with the composite measure of confidence (i.e. confidence ratings for all of the scenarios summed together), and also with confidence in the specific scenarios of wayfinding in a car and returning to a car park or bus station after exploring a new town. The frequency with which participants reported taking day trips to unfamiliar locations correlated specifically with confidence in returning to a place visited once before. It is impossible to determine categorically whether experiencing new environments influences wayfinding confidence, whether wayfinding confidence influences people's willingness to travel to new places, or whether the process is reciprocal. Either way, it seems that the extent to which strategies are related to confidence should be considered in the selection of the most promising strategies for use in the patient study.

Interestingly, reported confidence wayfinding in a car correlated with the use of landmarks and cognitive mapping. These are the same strategies that correlated with performance on the

route-learning task, which involved remembering a route that would be typical of a short car journey. It appears that, although the relationship between confidence and performance did not reach significance in this study, the use of strategies that are typically efficient is related to confidence. It may be that the sample size of the present study was simply not large enough to detect a relationship between confidence and performance.

The correlation between use of the look-back strategy and confidence in returning to a room in a large building is logical, and consistent with Heth et al.'s (2002) finding that using the look-back strategy improved route reversal performance. A lack of correlation between this technique and confidence in any other situation, along with the lack of correlation with performance in the route learning task, suggest that the look-back strategy is specifically useful in route reversal situations, and may not be advantageous to 'forwards' route learning or wayfinding in general.

The inverse correlation between map use confidence and use of distant buildings as landmarks was not predicted, but might suggest that individuals who are particularly poor at map reading are forced to rely upon the simple method of heading towards distant landmarks in order to navigate long distances.

Finally, the fact that males recalled the route with fewer errors than females is consistent with many studies demonstrating a male advantage in route learning (Collucia & Louse, 2004), although the effect did not reach significance in the present study. It is possible that this is due to the large variation in error scores across both male and female participants. Females relied

upon local landmarks to a greater extent than males, consistent with previous findings (Lawton, 1994). They did not, however, rely upon distal landmarks to a greater extent than males. Females also reported guessing more than males did, consistent with their poorer performance. Consistent with previous findings that males pay more attention to configurational information than females (McFadden et al., 2003), there was a trend towards greater reliance upon cognitive mapping, although this did not quite reach significance.

For the present study the gender difference in strategy use and the trend towards a gender difference in performance have important practical implications. They indicate the need to either control for gender differences or use a single sex sample in the patient studies for which this study served as a pilot.

6.4.1 Summary and Conclusions

The present study identified two strategies, landmark use and cognitive mapping, as particularly effective techniques for route learning. These strategies were correlated with performance on the VR route, and also with self reported wayfinding confidence. Confidence may be a particularly important construct, as it is related to the frequency with which individuals venture out into novel environments (although the direction of causality is open to interpretation). Based upon the findings from the present pilot study the following recommendations for the following patient studies were made:

- Use landmarks and cognitive mapping in patient study 2, in conjunction with errorless learning, because these are the strategies most clearly related to both good performance and confidence.

- Use an all-male sample when exploring strategy use, as males and females may produce qualitatively different data, which may need to be analyzed as two separate groups, reducing the maximum sample size available for any given analysis.

- Minimize the influence of proficiency using the control pad by having the experimenter control movement through the virtual town (under instruction from participants) rather than creating a cognitive load for participants unfamiliar with computer gaming control pads.

CHAPTER SEVEN

PATIENT STUDY ONE: ERRORLESS VERSUS TRIAL-AND-ERROR ROUTE LEARNING IN INDIVIDUALS WITH ACQUIRED BRAIN INJURY

7.1 Introduction

As discussed in Chapter 2, errorless learning is a technique of presenting information across acquisition trials in such a way that the learner is prevented from making errors, learning exclusively by repeated exposure to correct information. It can be contrasted with errorful or trial-and-error learning, and has been found to be particularly advantageous for people with various cognitive impairments, including ABI (e.g. Baddeley & Wilson, 1994; Wilson et al., 1994)

As discussed in Chapter 2, there is controversy surrounding the precise mechanism by which errorless learning derives an advantage over errorful learning, and in particular whether implicit or explicit memory is responsible (e.g. Page et al., 2006). Regardless of its modus operandi, however, errorless learning has been employed with considerable success in a variety of tasks. A majority of the early studies of errorless (and minimal-error) learning focused upon the learning of verbal material, and these are discussed in Chapter 2. The present study is interested in the potential of errorless techniques for improving performance on more practical, non-verbal tasks, and introduces findings from studies that have attempted to apply errorless methods to such tasks.

In one of the first studies to assess performance on practical tasks, with a series of single case studies, Wilson and colleagues found an advantage for errorless over errorful learning in programming an electronic personal organiser and recalling orientation information such as one's name and address (Wilson et al., 1994). However, in a group study, Evans et al. (2000) attempted to train participants in the use of an electronic organizer and failed to replicate the benefit of errorless advantage. The inconsistency in the findings of Wilson et al. (1994) and Evans et al. (2000) could be attributable to differences in procedure. For example, Evans et al. (2000) gave fewer learning trials and more test trials than Wilson et al. (1994), which could have resulted in the introduction and maintenance of errors during testing, especially if there had not been sufficient learning trials for information provided errorlessly to be consolidated in memory. It has also been suggested that errorless learning is not universally superior to errorful learning in rehabilitation, and that factors such as degree of impairment and difficulty of the task in hand (Evans et al., 2000; Riley & Heaton, 2004) may mediate the amount of benefit gained, with errorless learning being more effective when the task is particularly complex or the learner has particularly impaired memory.

Evans et al. (2000) also failed to identify an advantage for errorless over trial and error learning in two paper-based route learning tasks, although the possibility that ceiling effects prevented differences from emerging is cited (Evans et al., 2000). In light of the fact that Evans et al. (2000) also failed to replicate previous findings of errorless advantages in verbal learning tasks, it is also possible that feature(s) peculiar to their participants or procedures, not necessarily applicable to all scenarios or patients, prevented the emergence of errorless learning benefits. For example, the inclusion of a large number of participants with executive

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deficits (approximately 50%) may have meant that benefits, in terms of minimising distractibility for example, of the more active procedures used in errorful conditions countered the disadvantages of greater error rates. The relationship between executive function and errorless learning is addressed in Chapter 9. In addition, Evans et al. note that the explicit or declarative nature of their first route-learning task, in which participants were required to recall a route around a pictorial representation of a room, was unlikely to facilitate the use of implicit memory. The present study, therefore, assessed retention in way more likely to allow implicit or procedural memory to be used, by asking participants to direct the experimenter around the route.

The nature of the spatial tasks employed by Evans et al. (2000) also means that findings cannot necessarily be generalised to real world route learning. The tasks set involved memorising small scale, two-dimensional routes, and, in addition to the intuitive difference between paper-based and three-dimensional route learning tasks, there is empirical support for the idea that the cognitive mechanisms involved in spatial learning vary depending upon the physical scale of the stimuli (Hegarty et al., 2006). Performance on two-dimensional tasks in 'object space' does not correlate well with performance on tasks in large-scale three-dimensional 'environmental space' (Hegarty et al., 2006). Furthermore, people with impairment in real-world wayfinding following ABI do not necessarily show impairment on small-scale pencil-and-paper assessments of spatial ability (Aguirre & D'Esposito, 1999), possibly because different neural areas sub-serve the processing of large- and small-scale space (Kosslyn & Thompson, 2003; and Morris & Parslow, 2004, in Hegarty et al., 2006, p.153). The fact that errorless learning did not provide a benefit to learning on a small-scale

spatial task, therefore, does not necessarily indicate that it would not be effective in a larger-scale environment.

In support of the potential value of errorless methods for route learning in a large-scale environmental space, Brooks et al. (1999) employed errorless methods with great success in a single case study of a woman with severe route learning problems, in a three-dimensional virtual simulation of a hospital. Unfortunately, the design of the study did not allow for concrete conclusions about the contribution of the errorless methods to the success of the intervention.

Route learning is an important daily living skill, and route learning impairment is a common consequence of ABI (affecting from around 30% to around 80% of people with an ABI, according to Barrash et al.; 2000), and further research into the potential benefits for errorless learning, in large-scale realistic environments, is warranted. In addition to the fact that there does not appear to have been sufficient research into errorless route learning to discount its benefits, there is also a theoretical basis for expecting that it may be effective. Real world route learning is at least partially procedural, as it is possible to learn and recall routes under attention-demanding dual task conditions (Garden et al., 2002). Procedural learning is typically spared in ABI (Cavaco et al. 2004), and appears to be facilitated by errorless learning (Maxwell et al., 2001), so there is reason to believe that errorless learning could be advantageous in a procedural route-learning task.

The present study, therefore, aimed to compare the benefits of errorless and trial and error route learning for people with memory deficits owing to ABI in a task with good ecological validity. Assessing route learning in the real world, however, is problematic because difficulties can arise in controlling for familiarity with the test environment (Kirasic et al., 1984) and cues can change across test sessions, depending upon time of day or weather. Restricted mobility and physical fatigue may be a particular obstacle to real-world wayfinding with samples of participants with ABI. VR route learning is an increasingly popular substitute for real world environments, and offers a good compromise between ecological validity, experimental control, and practicality (e.g. Loomis et al., 1999). Numerous studies have demonstrated good equivalence between the real world and VR, described in detail in Chapter 4, and very good equivalence between wayfinding performance in the virtual environment used for the present study and in a real-world environment has also been demonstrated (see Chapter 5). Furthermore, virtual environments have also been shown to be clinically sensitive to the real-world wayfinding deficits of patients with memory impairments (e.g. Skelton et al., 2000). The present study, therefore, uses a three-dimensional virtual simulation of a large-scale environment in order to compare the benefits for route learning of errorless and errorful techniques.

Objective and subjective measures of memory and sense of direction, respectively, are also taken in order to provide an indication of how impaired participants are in terms of their general memory and of whether they consider their sense of direction to be poorer since their brain injury.

In summary, errorless learning is more effective than trial and error methods not only in many verbal learning tasks (Baddeley & Wilson, 1994; Hunkin et al., 1998; Squires et al., 1997; Wilson et al., 1994), but also across a range of practical tasks (Wilson et al., 1994). Not all studies have found universal advantages for errorless over trial and error learning (Evans et al., 2000), such as a study of spatial learning in a two-dimensional task (Evans et al., 2000). However, a single case study provides preliminary evidence for an errorless benefit in large-scale three-dimensional route learning (Brooks et al., 1999). Because route learning is an important everyday living skill, and one that is often impaired in ABI (Barrash et al., 2000), the present study sought to re-assess the benefits of errorless over errorful methods in an ecologically valid task with a group of people with memory impairments due to ABI.

7.2 Method

7.2.1 Design

A repeated-measures, within participants design was employed. All participants learned one route under errorless and one route under errorful conditions. The order of conditions was counterbalanced to control for potential practice or fatigue effects, and the allocation of routes to conditions was also counterbalanced, such that half the participants learned route A under errorless conditions and B under errorful conditions, and vice versa.

7.2.2 Participants

An a priori precision analysis indicated that recruitment of 17 or more participants would allow for detection of a large difference of 1 SD between conditions (2-tailed). Previous studies have found effects of this magnitude and greater for errorless learning in people with ABI (Kessels & DeHaan, 2003), and as the present series of studies aimed to identify techniques that would have real practical utility, power to detect effects of this magnitude was deemed sufficient.

Participants were 20 patients with acquired brain injury of sufficient severity to cause functional deficits requiring attendance at a rehabilitation centre. Participants were recruited through leaflets, posters and word of mouth, from an outpatients' rehabilitation unit at a Birmingham hospital and from regional branches of Headway day centres. Inclusion criteria were an ABI, subjective memory impairment, and some objective evidence of memory deficit, from neuropsychometric testing and / or route learning performance on the

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experimental task. Exclusion criteria were visual neglect and severe language difficulties. Only one potential participant was excluded on the basis of visual neglect, and one on the basis of severe language impairment. Demographic information for the final sample is provided in the results section, in table 7. All participants received an information leaflet explaining the details of the study (see Appendix E) at least 24 hours before giving informed consent (see Appendix F for a copy of the consent form).

7.2.3 Apparatus and materials

The apparatus was exactly as described in the virtual reality route-learning condition of Chapter 5 (see section 5.2.3.1).

Two routes were taken from a virtual simulation of the French town of Nice. The routes contained the same number of left turns, right turns, and 'straight-ahead' choices as each other, and the same number of T-junctions and crossroads as each other (see Appendix D for maps of the routes; the present study used routes A and B). They were also demonstrated, by pilot studies with neurologically healthy individuals, to be of equivalent difficulty. 16 participants, 8 males and 8 females, aged 18 – 53, mean 24.75 (S.D. 10.47) completed both routes under conditions very similar to the test conditions of the present study. A paired samples t-test revealed no significant difference in the number of wrong turns taken on the two routes during the test trial (t=.128, n=16, p= 0.900), with a mean of 7.06 (S.D. 6.4) errors made in route A and a mean of 6.88 (S.D. 5.63) errors made in route B.

A scale on which participants rated their current and their pre-morbid sense of direction, respectively, on an 8-point scale anchored at either end with the words 'poor' and 'good', was also administered. The questions were simply phrased 'overall, how would you rate your current sense of direction' and 'overall, how would you rate your sense of direction before your injury'. No further explanation was deemed necessary, as previous studies (e.g. Kato & Takeuchi, 2003, Cornell et al., 2003) have shown that people are familiar with the concept of 'sense of direction' and are able to rate it in a way that correlates with several objective measures of performance.

The Rey Complex Figure (Rey, 1941; Osterreith, 1944) and the list-learning subtest from the AMIPB (Coughlan & Hollows, 1995), described in greater detail in Chapter 9, were used as objective assessments of participants' visuo-spatial and verbal memory impairment.

7.2.4 Procedure

7.2.4.1 Errorless condition

Participants were asked to watch as the experimenter moved along a route through the virtual town, calling out directions at each junction. They were informed that they would see the entire route thus three times, before being returned to the beginning for a fourth and final time, when they would be asked to call out directions at each junction. They were told that any wrong directions they called out would be followed for 5 seconds, to give them a chance to change their mind, before the experimenter corrected their error. The instructions are reproduced verbatim in Appendix C.

Participants were also encouraged to ask the experimenter to look around at junctions (or elsewhere) if they so desired. This was in order to render the experience as similar to real-world navigation as possible, allowing participants to view the scenes they would choose to look at in the real world. A more effective way of doing this would have been to allow participants to control their own movement and viewpoint, but several participants would have been physically unable to use the control pad due to motor impairments, and, furthermore, pilot studies demonstrated that it was difficult for participants to concentrate on operating the controls and learning the route simultaneously.

Participants then watched the screen as the experimenter proceeded to move along the routes calling out directions. The experimenter pointed out each junction upon approach and stated the action to be taken, before executing it. All instructions were given in the same format; i.e. 'we are approaching [a crossroads / a turn-off to the right / a turn-off to the left] we need to [turn right / turn left / go straight ahead] here.' This was intended to create a consistent learning procedure for every participant, and to ensure that each junction was presented as equally salient. Instructions were presented in the present tense, first person plural, in an attempt to maximise participants' involvement in the task.

After viewing the route three times, participants were returned to the start-point, reminded of the test trial procedure, and testing began.

7.2.4.2 Errorful condition

As in the errorless condition, participants were asked to watch as the experimenter moved along a route and called out directions. They were informed that after they had viewed the whole route once through, they would be returned to the start and asked to try and direct the experimenter around the route, twice, in order to help them learn it. After these two practice trials, they were told they would direct the experimenter around a final time, and that this time would be a test of how much of it they had learned. They were informed that, when incorrect, their directions would be followed for five seconds (during which time they were free to call out corrections) before being corrected by the experimenter. I.e. the learning trials and test trial in the errorful condition were identical to the test trial in the errorless condition, so participants in the errorful condition were likely to experience errors throughout learning whereas participants in the errorless condition would not be able to make any errors until the test trial. The instructions given in the errorful condition are reproduced verbatim in Appendix C.

The procedure in the errorful condition did not follow exactly the format typically employed in the verbal learning literature; whereas Baddeley and Wilson (1994) induced errors from the very first acquisition trial in their errorful condition, by asking participants to try and guess words, the present study provided participants with a correct demonstration of the entire route on the first acquisition trial, only allowing errors to occur during the second and third learning trials. This procedure may be expected to result in less pronounced differences between errorless and errorful conditions, because it does not induce as many errors, but was favored for its ecological validity; in reality, people rarely attempt to learn a route for the first time by

guessing, whereas it is quite typical for someone to be shown a route once and make errors when re-attempting it without assistance.

After they completed one route learning condition (consisting of a demonstration trial, two learning trials and a test trial), participants were administered psychometric tests during a break of at least fifteen minutes (see Chapter 9 for more details and full results of these), before completing the remaining route learning condition.

7.3 Results

Participants' demographic details and scores on selected memory tests are summarized in table 7, broken down into groups of different ABI aetiology. Full neuropsychometric test results are provided in Chapter 9. Participants all had demonstrable memory impairment on neuropsychometric tests. On the main five immediate recall trials of the AMIPB list learning test, 12 participants scored in the abnormal range (below the 2 standard-deviation cutoff), 5 scored in the well-below-average range, and 2 in the below average range. One participant did not wish to continue with the study so some neuropsychometric data were not available. However, this participant did score his current sense of direction as lower than pre-injury.

Participants' self reported sense of direction at the time of testing (mean=4.3, S.D.=1.78) was, overall, significantly poorer than their self-reported premorbid sense of direction (mean = 6.4, S.D.=1.66) (t=4.84, n=18, p <0.0005; partial eta^2 = .573).

Table 7: Participants' demographic details and scores on verbal and visual memory tests, broken down by aetiology.

Aetiology	N	Mean (SD) time since injury (months)	Mean (SD) age	Mean (SD) list learning t score		Mean (SD) Rey complex figure t score	
				Trials A1-5	Trial 6 (recall after slight delay)	Immediate recall	Delayed recall
Traumatic brain injury	8	206.38 (104.78)	43.25 (11.17)	25.80 (6.45)	24.33 (8.63)	27.64 (17.67)	26.29 (18.98)
Vascular disorder	6	30.33 (19.34)	49.50 (9.05)	23.98 (15.96)	38.11 (26.56)	33.50 (5.97)	29.50 (14.84)
Other	6	81.00 (50.88)	34.50 (12.51)	21.80 (10.19)	22.88 (7.31)	31.58 (18.75)	35.80 (20.73)
All	20	115.95 (104.73)	42.50 (12.03)	24.06 (10.23)	27.50 (15.60)	30.41 (15.49)	30.06 (17.90)

As shown in table 7, there was little difference between participants who acquired their brain injury via traumatic brain injury, vascular disorder, or other incident (this category included 5 participants who had a brain tumor and one whose injury was due to removal of a cortical cyst). The only statistically significant differences between groups of different aetiology were in age and time since injury. The sample of participants with stroke was significantly older than the sample of participants with 'other' brain injury (t = 2.38, df = 10, p = 0.039). The mean time since injury for the traumatic brain injury group was significantly longer than that of both the group with 'other' classification (t = 2.68, d.f. = 12, p = 0.020) and the group with stroke (t = 4.64, d.f. = 7.62, p = 0.002). The time since injury of the group classified as 'other' was also significantly longer than that of the group with stroke (t = 2.28, d.f. = 10, p = 0.046). No other differences approached statistical significance, and in particular there were no differences between groups on the number of errors made under errorless ($F_{(2,19)}$ = .279, p = 0.760) or errorful ($F_{(2,19)}$ = 1.87, p = 0.184) learning conditions, so all participants were analyzed as one sample.

A paired samples t-test revealed a significant difference between number of errors made under errorless conditions and errorful conditions (t= 2.631, d.f. = 20, p = 0.016; partial eta^2 = .267). The mean number of errors made during the errorful test trial, at 4.65 (S.D.2.35), was significantly higher than the number made under errorless conditions, at 3.4 (S.D. 1.54).

7.4 Discussion

Route recall in a virtual town was assessed after errorless and errorful learning in 20 individuals with memory impairment secondary to ABI, and was found to be significantly better under the errorless condition. This suggests that errorless learning can be beneficial for helping people with ABI to learn and remember routes around a VR town. Because a within-participants, fully counterbalanced design was employed, there is good reason to believe that the difference in performance between conditions is truly attributable to the learning procedures used, and not to confounding variables such as individual differences between patient samples.

Every effort was made to ensure that the errorless and errorful learning conditions were as similar as possible, with the exception of the presence or absence of errors. However, it is extremely difficult to vary only the amount of errors introduced into the learning condition, and as such it is conceivable that additional differences between conditions could have contributed to the observed result. For example, the errorless learning condition is less active than errorful learning, which may influence retention as a factor in itself. However, because active spatial learning is typically more effective than passive learning (Rose et al., 1999), this factor would have been expected to push results in the opposite direction than the observed errorless advantage. Another difference is that errorful learning exposes the participant to a great deal more stimuli than errorless learning. However, this is an intrinsic feature of errorful learning, and is a legitimate contributing factor to the effectiveness of errorless over errorful learning. These influences, therefore, are quite acceptable and do not invalidate the results,

although they can complicate the formation of theoretical models of the mechanisms of errorless learning.

The present study demonstrates, therefore, that errorless learning methods can be more effective than errorful learning in the practical task of route learning, when assessed in a simulated large-scale environment. This is consistent with previous findings of benefits of errorless learning in verbal memory tasks (e.g. Baddeley & Wilson, 1994), and with preliminary findings of benefits for errorless learning in a variety of practical tasks (e.g. Wilson et al., 1994). It is also consistent with the suggestion that part of the success of Brooks et al's (1999) VR route learning training regime for a woman with severe amnesia is attributable to the errorless technique employed.

The finding is inconsistent, however with the studies of Evans et al. (2000), which failed to demonstrate a benefit for errorless learning in two different route-learning tasks. It is possible this can be attributed to considerable differences in the nature of the route learning tasks employed in the two studies. The present route-learning task could be described as more procedural or 'data-driven' than the 2-D assessments used by Evans et al. (2000), and participants with memory impairments have been shown to perform better on data-driven tasks than on conceptually-driven tasks (Faulkner & Foster, 2002). Differing levels of task complexity may also explain the inconsistency. Extrapolating from findings that errorless methods tend to be more beneficial than the method of vanishing cues when tasks are harder or participants are more impaired (Riley et al., 2004), it is possible that our study demonstrated a benefit to errorless learning because there is more information processing

involved in learning a three dimensional route through a large environment than in learning a two-dimensional abstract route on paper.

The fact that the routes learned were completely new to participants supports the theory that errorless learning can facilitate the acquisition of novel associations, in addition to strengthening existing associations (Squires et al., 1997). Evans et al. (2000), however, failed to find a benefit for errorless learning in tasks requiring the forming of novel associations, such as learning to programme an organizer and memorizing a two-dimensional route. In explaining this finding, they refer to connectionist models of hippocampal and neocortical learning (e.g. McClelland et al., 1995), and suggest that errorless learning may facilitate implicit memory via strengthening existing cortical associations (akin to priming), but may not be effective in forming novel associations through repetition directly in implicit memory, at least not with the number of learning trials used in their study. The present study, however, found a benefit of errorless learning for novel information after only three learning trials, suggesting that the formation of novel associations via implicit memory is, in some circumstances, possible within a relatively small number of repetitions. It is possible that the relatively procedural nature of realistic route learning (Garden et al., 2002) rendered our task particularly amenable to implicit learning, contributing to the relatively rapid facilitation of memory through errorless learning.

Whether the present study demonstrates explicit recall is debatable. In verbal learning studies, such as that of Hunkin et al. (1998), explicit recall and the uncued recall of novel associations are, typically, synonymous. In the case of route learning, however, improved recall of a novel

route resulting from errorless learning does not prove, necessarily, that explicit recall has been facilitated. It could be argued that the junctions at which participants make their decisions act as recall cues in some way, or even that participants do not consciously know the correct turns, and feel as though they are guessing as they use implicit memory to complete the task. If participants were required to provide written directions for the whole route at the beginning, or to draw a map of the route from memory, in a more explicit test of recall, it is possible that performance would be much poorer, and may not be facilitated at all by errorless learning. In order to expand the theory surrounding errorless learning, future research could address the question of how much explicit knowledge is acquired during errorless route learning with such tests (although there are difficulties associated with scoring sketch maps which make this difficult, see page 21).

Future studies could also address the question of whether the errorless advantage for route learning would persist after a delay, as Evans et al. (2000) found that, in a free recall name-learning task, the benefit of errorless learning dissipated after a delay of just thirty minutes. This appeared to be due to the fact that interference from incorrect choices that were encountered during learning in the errorful condition disappeared during the delay. However, as discussed in Chapter 3, errorless learning does not work solely through decreasing false positive responses, so even if the interference that makes errorful learning particularly ineffective dissipates after a delay, errorless learning could still lead to superior performance through recollection of more correct information. While a recent study claims to demonstrate retention of errorlessly-acquired information over several weeks (Pitel et al., 2006), the fact that this is based upon a single case study and that there was no errorful comparison condition

means that further work is needed to confirm whether errorless learning really can enhance long-term retention.

In the field of route learning, in which information may be required months after it was learned, it is important to determine whether the benefits of errorless learning are preserved over time. As mentioned earlier, route learning might be classified as the sort of activity hypothesized by Evans et al. (2000) to benefit from a more stable enhancement through errorless learning, due to the fact that learned associations are less likely to be degraded by the experience of similar competing information during a delay. Empirical support for this theory would be valuable.

In terms of expanding on the practical applications for the findings, future work could also assess the benefits of errorless learning in a real-world route-learning task. While there is much evidence to support the ecological validity of VR route learning (see chapters 4 and 5), it would, nevertheless, be valuable to demonstrate an advantage of errorless learning in the real world with a sample of participants with ABI. It would also be of both practical and theoretical interest to determine whether errorless learning can be improved upon by combining the technique with additional mnemonic strategies. The study reported in the following chapter addresses this question.

The findings from the present study are likely to be applicable to a broad range of participants with ABI, as the sample comprised individuals with a range of ages, social backgrounds, and medical histories. Participants were not pre-selected to have isolated memory impairment or

any specific form of route learning deficit, with the intention that results should be applicable to a heterogeneous population of people with ABI with memory impairment. The results may not, however, be generalizable to females, as only one out of the twenty participants was female, and gender differences have been often observed in studies of route learning (Collucia & Louse, 2004).

7.4.1 Conclusions

Errorless learning was significantly more effective than errorful learning in helping participants with ABI learn a route through a VR town, demonstrating that it is can facilitate the acquisition of complex novel information and for improve performance on a practical, spatial-learning task. This is particularly exciting given the fact that route learning impairments are common in ABI (Barrash et al., 2000). The next chapter describes a study undertaken to investigate whether errorless learning of routes by people with ABI can be further improved by introducing additional strategies that have been shown to be effective in typical route learning by neurologically healthy individuals.

CHAPTER EIGHT

PATIENT STUDY TWO: DO MAP AND LANDMARK STRATEGIES INCREASE THE BENEFIT OF ERRORLESS LEARNING FOR PEOPLE WITH ACQUIRED BRAIN INJURY IN A ROUTE LEARNING TASK?

8.1 Introduction

8.1.1 Overview

The study reported in the previous chapter found errorless learning to be significantly better than trial and error in helping people with ABI-related memory impairment to learn a route through a realistic VR town. Whilst the route-learning task was chosen specifically for its ecological validity, the errorless learning process itself was relatively contrived, and anecdotal evidence suggested that it was not very engaging for participants. There are many naturalistic strategies that are used in real life for learning routes, and there is a great deal of literature discussing the relative popularity and importance of these strategies (e.g. Kato & Takeuchi, 2003). In line with recent research investigating the potential for combining errorless learning methods with additional techniques and / or types of information (Evans et al., 2000; Kalla, Downes & van den Broek, 2001), the present study, therefore, sought to investigate the potential for combining standard errorless methods with naturalistic route-learning techniques.

This introduction first reviews findings from studies into rehabilitation of people with memory impairment that have moved beyond simple errorless learning to combine the technique with additional methods. Reasons for predicting improved performance with

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multiple strategies, based on several information processing theories (developed primarily with neurologically healthy samples) are then given. The most appropriate strategies to combine with errorless learning in order to aid route memorisation are then discussed, with reference to the wayfinding literature and the findings from Chapter 6.

8.1.2 Combining errorless learning with additional methods

Evans et al. (2000) studied errorless learning techniques across a range of tasks and under a range of conditions. Standard errorless learning procedures were more effective than trial and error methods in face-name learning only when tested with cued recall, not when tested with free recall. However, when the errorless learning procedure was modified to include an imagery mnemonic (requiring the participant to mentally trace the first letter of a person's name across their facial features) it also resulted in more effective free recall than did the trial and error condition, probably through acting as a cue to recall, embedded in the face stimulus. (Evans et al., 2000) Thus suggests that simple errorless learning can be improved upon by combining it with additional mnemonic strategies.

Evans et al. (2000) found in a 'stepping-stone' task, however, where participants were required to learn a route across a two-dimensional grid of patterned squares, that combining errorless learning with an additional learning technique known as chunking (in which to-be-learned information is broken down into manageable chunks) failed to improve performance above that observed under trial and error conditions (Evans et al., 2000). This may be because chunking is not an effective procedure to combine with errorless learning, or it may be that the task itself is not suited to errorless learning under any conditions.

Another technique that has been used successfully in conjunction with errorless learning is the pre-exposure technique (Kalla et al., 2001), which involves presenting a stimulus (in this case, an image of a face) to the participant for approximately 5-10 seconds before presenting the associated to-be-learned stimulus (a name). This procedure used with errorless learning led to more effective recall than errorless learning alone, although evaluative judgments about the image were made during pre-exposure, and not when the image was simply observed passively. Kalla et al. (2001) suggest the benefit from combining errorless learning and pre-exposure is attributable to the fact that the former operates at the retrieval stage of processing, (i.e. through preventing interference when one attempts to retrieve a memory), while pre-exposure is works at the encoding stage of processing (by allowing the participant extra time to encode and consolidate a stimulus in memory before learning its association) (Kalla et al., 2001).

Whilst initial support for the effectiveness of combining errorless learning with additional techniques is mixed, the findings of at least some positive effects could be argued to provide proof that, in principle, it can be beneficial

8.1.3 Theoretical models of information processing – predictions for combining strategies

There are several theoretical arguments for predicting an advantage for combining errorless techniques with other methods. The levels of processing effect (Craik & Lockhart (1972), refers to the influence that the way in which information is attended to during processing has upon the ease with which it is later recalled. The general premise is that the deeper the

information processing the better the recall (Craik, 2002). In word learning, for example, words processed in a shallow way, by attending to their font size or colour are less well recalled than words processed more deeply by paying attention to their meaning (Craik, 2002). The levels of processing effect predicts that combining errorless learning with an additional strategy should result in better performance than errorless learning alone, if the additional strategy serves to encourage more elaborate encoding of the route. It is possible that the benefit of combining errorless learning with an imagery strategy, seen in Evans et al. (2000), is attributable to the induction of more elaborate processing. However, insofar as errorless learning is sub-served by implicit memory processes (see Chapter 3), the depth of processing effect may be attenuated or even eliminated. Studies have found that, unlike explicit memory tests, implicit tests of memory do not appear to be influenced by the depth of processing or the amount of attention paid to stimuli during learning (Szymanski & MacLeod, 1996). Furthermore, there has been little direct research into how the levels-of-processing theory applies to individuals with ABI. In one study that did address the issue, Goldstein, Levin, Boake and Lohrey (1990) found evidence that the levels of processing effect did occur in a sample of 16 people with ABI, although the magnitude of the effect was smaller than that seen in control participants. This is possibly due to the fact implicit learning, relied more heavily upon in ABI (Page et al., 2006), may not be subject to the effects of depth of processing (Szymanski & MacLeod, 1996). This suggests that increasing the depth of processing of route information by combining errorless learning with additional strategies should improve recall, but that the effect may be relatively modest.

The dual coding theory (Paivio, 1971, in Clark & Paivio, 191), and the multimedia learning theory (Mayer, 1989; in Mayer, 1997) also predict that learning from a wide range of stimuli will result in better recall than learning from one type of information. Paivio's dual coding theory highlights the fact presentation of material in both verbal and visual modalities promotes more stable encoding of information and better recall than presentation in one modality. Similarly, the multimedia learning theory emphasizes the impact of presenting to-be-learned stimuli in diverse formats (e.g. text and pictures) upon recall. These theories could be thought of as charting the importance of 'breadth' of processing, in contrast to the 'depth' of processing focus of Craik et al. (1972). According to the dual coding and multimedia learning theories, combining errorless learning techniques with additional strategies should lead to more effective recall if it means that information is presented in a greater number of formats and / or multiple sensory modalities are used to process the information. As with the levels of processing theory, however, the importance of dual coding and multimedia presentations has not been explicitly studied in people with memory impairments, particularly in conjunction with errorless learning. It is possible that changes in the memory processes of people with ABI-related cognitive impairments will result in these manipulations bringing no clear benefit.

The benefit associated with active over passive processing that some studies of route learning have demonstrated (Farrell et al., 2003; Rose et al., 1999) may also contribute to an advantage for combining errorless learning with additional strategies. The use of strategies would, intuitively, be expected to increase the active involvement of participants in the learning experience. However, one problem with encouraging active processing in participants with

memory impairment the greater opportunity for error it often affords; both Komatsu et al. (2000) Riley et al. (2000) suggest that one reason why errorless learning is sometimes more effective than the method of vanishing cues, despite the fact that the method of vanishing cues is the more active of the two, is that more errors are possible with vanishing cues. However, learning conditions in which errors are fully prevented yet active processing is encouraged, as in the present study, should be expected to be most beneficial to people with memory impairments.

In summary, several theories converge to predict that combining errorless learning with additional strategies will be beneficial. However, very few of these theories have been directly applied to people with ABI, so there is a possibility that changes in the information processing and memory functions of such individuals will result in a different pattern of results than is typically observed in neurologically healthy individuals, particularly given the greater reliance upon implicit memory for people with ABI (Page et al., 2006).

Whilst theoretical approaches from information processing literature are called upon in explaining the decision to combine errorless learning with additional strategies, the aim of the present study is not to empirically test the validity of various theories. The study aims, rather, to investigate ways to further improve the practical benefits of errorless learning seen in the everyday task of route learning. Towards this end, the literature on human wayfinding was also a key resource, discussed below.

8.1.4 Route learning techniques: Choosing strategies to combine with errorless learning

As discussed in Chapters 2 & 6, people use a range of strategies in their everyday lives to help them remember routes, such as turn sequence memorization; use of various types of landmarks; cognitive mapping; dead reckoning; and the use of cardinal reference points (Lawton, 1994). These techniques vary in popularity (Lawton & Kallai, 2002), and effectiveness, as demonstrated by direct empirical investigation into the benefits of promoting the use of specified strategies (e.g. Heth, Cornell & Flood, 2002; Tom & Denis, 2003), and indirect evidence that good and poor wayfinders report spontaneously employing different techniques (Kato & Takeuchi, 2003).

One of the most investigated and yet still controversial individual differences in wayfinding is gender (Collucia & Louse, 2004). Gender differences in strategy use, if not overall performance, are widely reported (Collucia & Louse, 2004; Gwinn et al., 2002), and were also demonstrated in Chapter 6. Because the present study sought to examine the relative effectiveness of wayfinding strategies, and a gender effect was deemed likely, therefore, the decision was made to study a single-sex sample. An all-male sample was selected, in light of the greater incidence of head injury in males than females, at a ration of approximately 2:1 (Hospital Episode Statistics Online, 2004-2005), making male participants more readily available and results from an all-male sample generalizable to a greater proportion of the population with ABI. Ideally, it would have been interesting to recruit a similar number of male and female participants, to allow for a comparison between sexes. However, the gender difference (or lack of) in wayfinding is a complex topic, beyond the scope of the present study.

The first strategy selected to combine with errorless learning in the all-male sample was landmark use, one of the most popular and widely used route-learning strategies (e.g. Cornell et al., 2003). The study reported in Chapter 6 confirmed that, in our virtual reality route-learning task, landmark use was, on average, the most popular strategy of all, and that use of landmarks correlated with both performance on the route learning task and self-reported wayfinding confidence. Landmark use was chosen, therefore, for combining with errorless learning because it is an intuitive strategy that people rely on spontaneously and report finding useful (Michon & Denis, 2001); helping people use landmarks effectively has been shown to improve route recall, particularly in males (Gwinn et al., 2002); and people who perform well on wayfinding tasks appear to use landmarks more than those who do not perform so well (Cornell et al., 2003; Kato & Takeuchi, 2003; Lloyd, Chapter 6).

Furthermore, combining landmark use with errorless learning produces a learning condition fitting several of the effective learning criteria suggested by theoretical models described above. Firstly, drawing participants' attention to landmarks is likely to increase the depth of processing of the stimuli. If junctions are the target stimuli in the route-learning task, and errorless learning simply pairs junctions with actions, introducing descriptions of landmarks at those junctions should result in more elaborative processing. Secondly, while even the simple errorless learning condition could be described as involving multimedia presentations, as the input from viewing the route on the screen is visual, and the route directions called out are verbal, a technique drawing attention to landmarks on screen could also be argued to increase the involvement of both visual and verbal information in learning. Finally, asking

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participants to notice specific landmarks could also, possibly, be expected to increase their active involvement in the route-learning task (although this is a speculative assumption).

It could be argued that, being such a widely used strategy, a landmark memorization instruction will not afford any extra benefit to an errorless learning condition, as a majority of participants will already be employing such a strategy. However, several factors influence the success of landmark use as a route-learning technique, and the experimental manipulation uses information from the literature to produce a technique that should, theoretically, be particularly effective; hopefully exceeding the benefit of spontaneous landmark use by participants in the simple errorless condition. The factors taken into consideration in selecting the most appropriate landmark strategy are discussed in the method section. The present study uses examples of both global and local landmarks (see page 9 for a definition) because (a) there is evidence for the effectiveness of each, and (b) this increases the number of good landmarks available on the chosen routes.

The second naturalistic route-learning strategy to be combined with errorless learning was cognitive mapping. Cognitive mapping has parallels with, but is not the same as, the process of using a concrete, physical map to guide navigation (Tversky, 1993). Cognitive mapping refers to the process of forming a mental representation of the configuration of the environment from a survey (bird's-eye) perspective. This can be particularly helpful when one needs to formulate a short-cut, or calculate the direct ('as the crow flies') distance or direction from one point on a route to another (e.g. Cornell et al., 2003), and Chapter 6 also found that reliance upon cognitive mapping correlated with performance in straightforward route

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learning, wayfinding confidence, and the frequency with which a person travels to unfamiliar places.

While cognitive mapping is a less popular strategy than landmark memorization, the findings of the pilot study, along with findings in reported in the literature that it is a strategy characteristically used by good route-learners (Cornell et al., 2003), suggest that it may be particularly effective. Combining cognitive mapping with errorless learning also results in a learning condition that should be effective based on several of the theoretical models described above: it could be expected to result in 'deeper' processing of the information than simply viewing the route, which should enhance recall (Craik & Lockheart, 1972, Craik, 2002); asking participants to keep track of their position on a map of the route (an activity involved in encouraging cognitive mapping, see Method section, below) might be expected to increase active involvement in the learning process, without introducing errors, which should also enhance recall (Riley et al., 2000); and presenting information in an additional format, i.e. a two-dimensional map in addition to the verbal instructions and the visual presentation of the route on screen used in the errorless condition, should also lead to improved performance based on the multimedia and dual coding theories of information processing (Paivio, 1971; Mayer, 1989)

There is little information in the literature on how to get individuals to employ a cognitive mapping strategy. Allowing free exploration of a virtual environment has been used as a means of encouraging people to form a cognitive map of the area (Spiers et al., 2001), but as the present study is specifically interested in route-learning this method was not appropriate.

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Instead, it was reasoned that the most obvious method was to present a physical map of that environment. For the cognitive mapping strategy condition, therefore, participants were presented with a drawn map of their route, which they were to consult during learning trials.

Participants were also asked to rate their pre- and post- injury 'sense of direction' on the scale introduced in the previous chapter (page 124-125), to give an indication of whether the sample was representative of people reporting deficits in their real-world wayfinding ability.

8.1.5 Summary

Based on some promising results from studies that have started to look at expanding errorless techniques to encompass additional methods (Evans et al., 2000; Kalla et al., 2001), and several information processing theories (Craik & Lockheart, 1972; Mayer, 1989; Paivio, 1971), it was predicted that combining errorless methods with additional learning strategies would result in better route-learning performance than simple errorless learning alone. Based on the wayfinding literature and the findings of the pilot study reported in Chapter 6, the popular strategy of landmark use and the less widely favored but effective technique of cognitive mapping, favoured by strong wayfinders, were selected to be combined with standard errorless learning methods. It was predicted that errorless learning combined with either strategy would result in better recall than errorless learning alone, but no predictions were made as to whether one combination would be better than another.

8.2 Method

8.2.1 Design

A within-participants counterbalanced design was employed, with all participants learning one route under simple errorless conditions, one under errorless conditions combined with a landmark memorisation strategy, and one under errorless conditions combined with a cognitive map strategy. The order of conditions was counterbalanced in a Latin Square design, with each of the three conditions administered first, second and third an approximately equal number of times. The allocation of routes to conditions was also counterbalanced, so that each route was presented in each condition an equal number of times. Because of the large number of possible order, condition, and route combinations, the order in which routes were presented could not be fully counterbalanced, but this was seen as the variable least likely to have any impact upon performance.

8.2.2 Participants

An a priori precision analysis was carried out in order to determine how many participants would be required to detect an effect large enough to have practical utility, as the aim was to determine whether combining errorless learning with additional strategies would result in a great enough advantage to merit the application of more complex techniques in a rehabilitation setting. For sufficient precision to detect an effect size of one standard deviation or more between conditions (2-tailed), a sample size of at least 17 was required. A recent meta-analysis reported effect sizes for observed benefits of errorless learning exceeding one standard deviation in several studies with people with ABI (Kessels & DeHaan, 2003).

Although this study was not comparing errorless and errorful learning, as the studies reported in Kessels and DeHaan (2003) it was deemed reasonable to hope to demonstrate a similar effect size to these studies, as an advantage of similar clinical utility to that of errorless over errorful learning would demonstrate that the naturalistic techniques were worthwhile additions to the basic errorless learning methodology.

Participants were 18 males with acquired brain injury of sufficient severity to cause functional deficits requiring attendance at a rehabilitation centre, none of whom had taken part in the previous study. Demographic details are provided in table 8. Recruitment methods and inclusion criteria were exactly as described for the previous study (pages 123-124). All participants received an information leaflet explaining the the study (see Appendix E) at least 24 hours before giving informed consent (see Appendix F for a copy of the consent form).

8.2.3 Apparatus and materials

The apparatus was exactly as described in the virtual reality route-learning condition of Chapter 5 (see section 5.2.3.1).

As in the previous study The Rey Complex Figure (Rey, 1941; Osterreith, 1944) and the list learning subtest from the AMIPB (Coughlan & Hollows, 1995) were used as objective assessments of participants' visuo-spatial and verbal memory impairment, and participants were also asked to rate their current and their pre-morbid sense of direction on the 8-point scale described in the previous study (pages 124 to 125).

Three equivalent routes were taken from a pool of six overtly equivalent routes, which were compared in a pilot study. All six original routes were equal in the numbers of lefts and right turnings taken and passed by, and in the numbers of crossroads and T-junctions encountered. However, because of the possibility that subtle differences between routes, for example in the number of useful landmarks or configuration of streets, would influence their difficulty levels, a pilot study with neurologically healthy controls was carried out to assess the equivalence of the routes more thoroughly. All participants learned three of the six routes, allocated pseudo-randomly, and a between-participants comparison of error rates across all six routes identified three routes that resulted in very similar mean error rates. One route, completed by 40 participants, had a mean error rate of 5.17 (S.D. = 3.57), a second, completed by 40 participants, had a mean error rate of 5.08 (S.D. = 4,26) and a third, completed by 32 participants, had a mean error rate of 5.06 (S.D. = 3.71). Paired samples t-tests were then conducted using data from participants who had completed at least two of the three similar routes (hereafter called routes A, B and C), and confirmed that there were no significant differences in errors made on routes A and B (t = .13, d.f. = 15, p = .90), A and C (t = .76, d.f. = 15, p = .46) or B and C (t = -.05, d.f. = 14, p = .96).

8.2.4 Procedure

8.2.4.1 Errorless condition

The standard errorless learning condition was exactly as described in Chapter 7 (page 125).

8.2.4.2 Errorless learning with landmark memorization

An equivalent number of landmarks were selected for each route, and effort was made to ensure that (a) the landmarks used were as useful as possible, by using various selection

criteria cited in the literature (e.g. Lynch, 1960; Raubal & Winter, 2002; Vinson, 1999), and (b) salience of landmarks across routes was as similar as possible. The salience of a landmark is influenced by a number of factors (e.g. Lynch, 1960; Raubal & Winter, 2002; Vinson, 1999). Generally, salience is greatest when a landmark is large, of a distinctive colour, texture or shape; and positioned at a route decision point (junction), but these features can interact.

The primary criterion used in selecting landmarks was position. Several researchers have commented on the importance landmarks located at junctions or route decision points (e.g. Lynch, 1960; Raubal & Winter, 2002; Vinson, 1999). Studies with neurologically healthy individuals typically expect participants to learn the association between a landmark and a turn, such that they will know, for example, to turn right at the red building. In order to minimize the amount of information to be recalled, the present study specifically selected landmarks that were located either in the street that the participant needed to select, or at the end of that street. In this way, it was reasoned participants would only need to recall landmarks (and not the direction of the turn also), because the required action would always be to head towards them, reducing the memory demands of the task.

Participants were informed that they would be shown around a route three times, with landmarks pointed out at useful points, before being asked to direct the experimenter around the route from memory. The exact instructions are reproduced in Appendix C.

During the learning trials, every time a landmark was pointed out, the experimenter used the following statement, whilst physically pointing at the landmark on screen: *'Notice the [insert landmark description] here. We need to [walk past / head for] this landmark'*.

8.2.4.3 Errorless learning with cognitive mapping

A map of each route was prepared, on which all of the sections of roads to be traveled along were represented, along with intersecting roads, in order to give participants an overview of the configuration of streets along and around their route. The route was marked on the map by shading. Figure 7, below, shows the map of route C, as an example, and the maps for routes A and B are reproduced in Appendix D.

Figure 7: Map of route C, with route shown shaded

The map was visible to participants throughout the learning trials, in order to maintain as much consistency with the landmark condition, in which landmarks were continually available, as possible. To the same end, a participant's attention was drawn to the map (by the drawing of an arrow on it) at the same number of points as landmarks were pointed out during the landmark condition. The map was presented in 'forward up' orientation, i.e. the map was moved at each turn so that the direction of travel was always towards the top of the page as it

lay in front of the participant. This decision was based on evidence that this is the most effective presentation when a map is used concurrently with route following, whereas 'North-up' is most effective orientation for a map presented prior to route following (Aretz & Wickens, 1992, in Darken & Peterson, 2001).

Participants were informed that they would be shown around a route three times, with the experimenter pointing out their position on a map of the route every few turns. They were also told that the map would be rotated at each turn to maintain a forward up view. They were warned that the map would only be available during learning trials, and that they would not be able to refer to the map when they were tested on their memory for the route. The exact instructions are reproduced in Appendix C. Each time they were shown the map during learning trials, participants were told; 'This is where we are on the map *[experimenter points]*, and this is the direction we are moving in *[experimenter draws an arrow]*'.

8.3 Results

Participants' demographic details and scores on selected memory tests are summarized in table 8 (full neuropsychological test results are provided in Chapter 9). Participants all had demonstrable memory impairment on neuropsychometric tests. On the main five immediate recall trials of the AMIPB list learning test, ten participants scored in the abnormal range, five scored in the below- or well-below- average range, and three in the average range. Of the three participants who scored in the average range on the main list-learning test, two were performing well below average on the final recall trial, which is administered after a small delay. Memory impairment was demonstrated for the participant who was in the average range on both immediate and post-delay list learning tests by performance in the abnormal range on the Rey complex figure visual memory test.

Table 8: Participants' demographic details and scores on verbal and visual memory tests, broken down by aetiology.

Aetiology	N	Mean (SD) time since injury (months)	Mean (SD) age	Mean (SD) list learning t score		Mean (SD) Rey complex figure t score	
				Trials A1-5	Trial 6 (recall after slight delay)	Immediate recall	Delayed recall
Traumatic brain injury	12	152.67 (148.36)	46.08 (14.79)	26.19 (14.58)	24.93 (14.95)	35.31 (20.80)	29.00 (26.62)
Vascular disorder	4	80.00 (106.86)	47.75 (14.93)	35.08 (13.65)	33.50 (17.81)	26.75 (20.83)	23.25 (18.46)
Other	2	48.50 (50.20)	49.00 (8.49)	33.00 (6.65)	20.95 (3.18)	28.50 (10.60)	10.0 (14.14)
All	18	124.94 (134.58)	46.78 (13.65)	28.92 (13.75)	26.39 (14.77)	32.49 (19.35)	25.41 (23.64)

Participants' subjective reports of 'sense of direction' also suggested that they experienced memory impairment in wayfinding, with the mean self-reported sense of direction at time of testing being 4.44 (SD 1.84), and the mean pre-morbid estimates of sense of direction being 6.75 (SD 1.50). A paired-samples t-test confirmed that this difference was significant (t = 5.59, df = 17, p <0.0005; partial eta^2 = .65), although these sense of direction estimates failed to correlate with objective measures of route learning performance under any conditions (p>0.05).

Table 9 shows the mean number of errors made in the three learning conditions (out of a maximum possible 14 errors, if a wrong turn were taken at every single junction). A one-way repeated measures ANOVA revealed no significant effect of learning condition on number of route recall errors ($F_{(2,34)}$ = 0.01, p = 0.99; partial eta^2 = 0.00).

Table 9: Performance under different route learning conditions

Learning condition	N	Mean route recall errors	Standard Deviation	Range
Simple errorless learning	18	3.44	2.18	1 - 7
Errorless learning with landmark strategy	18	3.39	2.27	0 - 8
Errorless learning with cognitive mapping strategy	18	3.44	2.01	1 - 7

8.4 Discussion

Eighteen individuals with memory impairment secondary to ABI learned three routes around a VR town, one under simple errorless conditions, one under errorless conditions combined with a landmark memorization strategy, and one under errorless conditions combined with a cognitive mapping strategy. There was no significant effect of learning condition on retention of the route, with landmark and cognitive mapping conditions contributing no extra benefit to a simple errorless learning technique.

The first possible reason for absence of benefit observed with the additional techniques is that the sample size of eighteen was too small to detect an effect. However, the sample size was based upon an a priori precision analysis that indicated that 17 or more participants would give sufficient power to detect a difference of one standard deviation or greater between conditions. While it is possible that more subtle differences between conditions would not be detected, the present study was interested in finding effects of incorporating new strategies with errorless learning that would be large enough to be practically beneficial. In order to justify the extra time and effort that would be required from both patients with ABI and rehabilitation therapists in order to implement naturalistic strategies in conjunction with errorless techniques, a significant benefit of at least one standard deviation was considered a reasonable minimum effect to demand. In other words, whilst the sample size used in the present study may have been too small to detect small differences between conditions, it is unlikely that any differences significant enough to have practical utility were overlooked.

It is possible that the lack of significant benefit for adding naturalistic techniques to errorless learning procedures is attributable to features of the route learning techniques. For example, it is possible that the landmark condition was not effective because participants did not select the landmarks themselves. In the same way that people are more likely to recall words generated by themselves in response to cues, rather than words provided by the experimenter (Slamecka & Graf, 1978), even when they have some memory impairment (Mimura et al., 2005) they may be less able to recall landmarks pre-selected for them by someone than they would be to recall landmarks that they identified themselves. However, there is evidence that spontaneous implementation of mnemonics is impaired in people with memory deficits (Richardson, 1995), so it may be the case that spontaneous use of strategies is also impaired.

It is also possible that some participants were unable to recognize the landmarks. One of the potential causes of route learning impairment in ABI, termed 'topographical agnosia' is an inability to distinguish between landmarks (e.g. Aguirre & D'Esposito, 1999). However, no participants mentioned impaired ability to recognize or distinguish between landmarks when asked, prior to the study, to describe any specific wayfinding difficulties they experienced. Nonetheless, there is a possibility that some participants had topographical agnosia yet lacked insight into their condition, so future studies may benefit from inclusion of a test to screen for landmark recognition deficits.

It is also conceivable that the landmark condition failed to afford any additional benefit because landmark memorisation is such a common strategy (e.g. Kato & Takeuchi, 2003) that participants also spontaneously used this technique in the basic errorless learning condition.

Although, as mentioned in the introduction, landmarks designed to be (theoretically) very useful were pre-selected, people may also spontaneously select very useful landmarks, and it is also possible that any benefits afforded by specially selected 'good' landmarks are counteracted by the fact that these landmarks are not self-generated (see above).

As regards the 'errorless learning plus cognitive mapping' condition, there are also several methodological issues that could potentially explain the lack of significant benefit over errorless learning alone. Firstly, the way in which the map was presented may not have promoted particularly effective processing. Based on findings in the literature that 'forward up' is the most effective orientation in which to present a map that is to be consulted whilst moving through an environment (Aretz & Wickens, 1992, in Darken & Peterson, 2001), the decision was made that the experimenter would rotate the map at each turn in order to maintain a forward up view. In retrospect, frequent rotation of the map may have contributed to the attentional demands. If a participant failed to watch when the map was rotated, they may also have struggled to keep track of their own position in relation to the map.

The decision to have the map on view throughout the learning trials was made in order to keep the landmark and map conditions as similar as possible; because landmarks were available frequently throughout the route. However, despite the instructions, it appeared that many participants failed to grasp the fact that the map was meant to serve as an aid to help them form a mental survey representation of the environment. Understandably, many participants attempted to use the map in an everyday sense, referring to it at every turn during learning trials, and often calling out directions, unbidded, to the experimenter. In other words,

it is not clear whether participants were really forming a mental map of the route during the supposed 'cognitive mapping' condition. If the map was presented prior to, after, or between learning trials, participants may have been more likely to use it in the way it was intended, as a cue to demonstrate the layout of the environment in order to help them remember it. As it was, participants relied heavily on the map as an on-line tool, and rather than developing a good memory of the route as a result, they failed to encode enough information about the route to be able to recall it when the map was taken away, such the map actually impaired performance (though this was not a statistically significant effect).

For both route-learning techniques, it is possible that the reason they do not improve errorless performance is related to the load they placed upon working memory. If referring to the map or concentrating on the landmarks was complex enough that it became, essentially, a concurrent task for participants, it is possible that this competition for limited resources negated any beneficial effects of the strategies. Neurologically healthy individuals in a complex route learning study showed performance decrements when given a concurrent working memory task to perform (Garden et al., 2002), demonstrating the negative impact that working memory load can have upon subsequent route recall. If increased working memory demand is responsible for the lack of benefit derived from landmarks and cognitive mapping, the possibility of improving route recall with naturalistic techniques remains valid, but it may be necessary to develop ways of using naturalistic route learning techniques with minimal working memory impact. The relationship between working memory capacity and performance in the strategy conditions is explored further in Chapter 9.

In addition to the methodological issues reviewed above that may have contributed to the lack of a benefit for combining errorless learning with additional route learning strategies, there are also possible theoretical explanations for the findings. As mentioned in the introduction, most of the models of information processing that were referred to in the predictions of improved recall with additional route-learning techniques were developed with reference to neurologically healthy individuals. It is possible that memory impairments disrupt the normal benefits afforded by more elaborative processing. It may be the case that errorless learning, a technique that many researchers believe works at least partially via implicit memory (e.g. Page et al., 2006), cannot be improved upon by being combined with techniques that are designed to improve the depth of processing, as depth of processing does not have an impact upon implicit recall (Szymanski & MacLeod, 1996). Cognitive mapping and landmark use are both explicit, in the sense that they require conscious processing and recollection, which may explain why they were ineffective in improving the performance of individuals with impairments in explicit memory. That is not to say that explicit memory techniques are of no use in rehabilitation in general; however, it may be the case that the benefits of errorless over errorful techniques, at least in the field of route learning, are such that they cannot be further increased by such explicit strategies. Page et al. (2006) draw a distinction between the theory that errorless learning is totally sub-served by implicit memory, and the theory that it derives its benefit over errorful learning from implicit memory.

There are so many variables potentially responsible for the lack of benefit derived from combining errorless learning with naturalistic route learning strategies that it is not possible at this stage to draw any firm conclusions. The lack of benefit for additional strategies could

indicate that errorless learning, which is thought by many to work via exploitation of spared implicit memory, cannot be improved through the addition of techniques that rely more heavily upon explicit memory capacity. However, it is also possible that the techniques do have the potential to enhance the benefits of errorless learning, but their benefits are counteracted by the negative effect of demands made upon working memory. It is also conceivable that the lack of effect of naturalistic route learning techniques is attributable to specific problems in the way the techniques were implemented, for example, that the map condition did not efficiently promote cognitive mapping, or that the landmarks pointed out were not consistent with the landmarks participants would have chosen for themselves.

The present study highlights numerous potential avenues for future research, particularly as methodological issues surrounding the learning conditions in the present study preclude concrete conclusions about the value (or lack thereof) of increasing depth of processing in people with memory impairment at this point. The discrepancy between the value of elaborative processing observed in people with no neurological impairment and the lack of benefit derived from such processing in the present study merits further investigation. Future studies should ensure that the techniques for improving depth of processing are easy to implement, with minimal working memory demands, but also that they encourage active involvement in the learning episode.

Route learning is, in many ways, well suited to the investigation of combining errorless learning with additional techniques. There are numerous techniques that can be employed, VR environments can be used in order to facilitate multiple repetitions in errorless learning conditions, and it is an area in which many people with ABI experience impairment, such that

finding the most effective combinations of techniques has good practical applications. However, there is controversy over the relative effectiveness of various strategies for route learning, even in neurologically healthy individuals (e.g. Aginsky et al, 1997), and individuals with ABI may be specifically impaired in the use of one or more techniques, depending on their profile of cognitive impairment (see the following chapter for more detail). It may be more parsimonious, therefore, for future studies to first establish the potential for incorporating errorless techniques and explicit methods for improving depth of processing with simpler practical tasks, such as basic domestic activities like as making tea or washing up.

In the meantime, as far as the improvement of route learning techniques goes, however, it may be worthwhile developing techniques to add to errorless learning that can capitalize on preserved implicit memory. The imagery mnemonic used by Evans et al. (2000), where participants imagined the shapes of the first letters of people's names superimposed on their faces in order to cue recall, could be applied to landmark use in route learning. If participants were encouraged to identify shapes of arrows or of the letters 'r' or 'l', to indicate right and left turns, respectively, superimposed upon landmarks, they may be able to use this to cue route recall.

8.4.1 Conclusions

The present study does not allow for any direct conclusions about the effectiveness of combining errorless learning with additional naturalistic strategies for route learning. However, one might argue that it demonstrates that learning of novel information after ABI is

less easily facilitated than in neurologically healthy individuals. Learning conditions were developed in accordance with literature on general information processing models and findings from route learning studies, which should, theoretically, have boosted retention on several levels. Whether the learning conditions did not work because participants were unable to use explicit memory, because of practical features of the learning conditions, or whether it was due to demands upon working memory counteracting any benefits, it seems that (as might be expected) there are many pitfalls to beware of in implementing memory enhancing techniques in people with ABI.

CHAPTER NINE

PATIENT STUDY THREE: COGNITIVE ABILITY AND ROUTE LEARNING PERFORMANCE

9.1 Introduction

9.1.1 Overview

A knowledge of individual cognitive deficits in people with ABI is important for rehabilitation purposes as this can help to explain the reason people may have difficulty carrying out various every day tasks and also suggest the most appropriate rehabilitation strategies (Chaytor & Schmitter-Edgcombe, 2003).

A significant number of people with ABI (Barrash et al., 2000) are impaired in everyday route learning ability, and thus an investigation of the relationships between neuropsychological test scores and route learning performance may: facilitate the early identification of people likely to experience difficulties, provide explanations to those who are already experiencing difficulties and, most importantly, help to identify appropriate rehabilitation techniques for that person.

Exploring the relationships between measures of cognitive function and performance on route learning under different conditions may also clarify whether there are other factors that should be considered when deciding upon strategy. It is possible for example, that the nature and context of the task and the way it is being taught, is equally as important as the individual's

cognitive profile which would mean that the choice of strategy should vary depending on a variety of factors.

A small number of studies have expressly addressed the ecological validity of neuropscyhological tests in predicting wayfinding or route learning performance (Fields & Shelton, 2006; Nadolne & Stringer, 2001). Several other studies have assessed the relationships between wayfinding or route learning performance and neuropsychological test scores as part of wider research questions, some with neurologically unimpaired participants (Cutmore et al., 2000; Moffat et al. 1998, 2001; Pazzaglia & De Beni, 2001), others with samples of participants with ABI (e.g. Uc et al., 2004a). A summary of these studies is shown in table 10 where it can be seen that studies often focus upon one or two types of test (e.g. mental rotation or visual memory) and the number of cognitive skills that are measured within one study is sometimes limited. Therefore, there is a need for a more thorough exploration using a greater range of measures. In order to explain the rationale for the present study, there follows a review of the observed relationships between neuropsychological test scores and wayfinding ability, drawing upon findings from all of the aforementioned types of study, structured according to the category of cognitive abilities assessed. This is followed by a review of the literature relating to the interaction between cognitive deficit, learning technique and strategy use.

Table 10: Summary of findings from studies administering wayfinding tasks and neuropsychological tests

Study	N	Ppts	Wayfinding task(s)	Neuropsychological Tests	Skill tested	Related to wayfinding performance?
Cutmore & al (2000)	37 (all f)	NH	Distance estimation in VR passages	Block design	Visuo-spatial ability (VS-A)	Yes
Fields & Shelton (2006)	40 (20m, 20f)	NH.	Judgments about relative directions of landmarks within a VR park environment.	Three mountains	Perspective taking ability	Yes
				VMRT	Mental rotation	Yes
				Money Road Map Test	Egocentric mental rotation	Yes
				Spatial Perspective	Egocentric perspective taking	Yes
				Spatial Span	Spatial working memory	Yes
				DSMT	Speed of processing	No
				Reading passages	Language skills	No
				Word span	Verbal working memory	No
Maguire et al (2003)	26 (all m)	NH	VR navigation, scene recognition & sketch-mapping	CTRMT	Visual memory	Yes, scene recognition
				Delayed Story Recall	Verbal memory	No
Moffat et al (1998)	74 (40m, 34f)	NH	Solving a basic VR maze (homogenous lengths of passageway)	Money Road Map Test	Egocentric mental rotation	Yes, time & errors
				GZSO Test	Mental rotation	Yes, time & errors
				VMRT	Mental Rotation	Yes, time & errors
				Advanced VocabTest	Vocabulary	Yes, time & errors
				COWAT	Verbal fluency / executive function	Yes, time (females only)
Moffat et al (2001)	117 (68m, 49f)	NH	Solving a VR maze containing basic landmarks.	BVRT	Short term visual memory	Yes, time, errors & accuracy
				Digit span	Verbal working memory	Yes, backwards DS & time
				Similarities (WAIS-R)	Verbal ability	No
				Card Rotations Test	Mental rotation	Yes, time, errors & accuracy
				CVLT	Verbal memory	Yes, time & errors
				PMA Vocabulary Test	Verbal knowledge / vocab	No

Table 10: Continued

Study	N	Ppts	Wayfinding task(s)	Neuropsychological Tests	Skill tested	Related to wayfinding performance?
Nadolne and Stringer (2001)	31	Stroke	Indoor route recall & landmark direction estimation	Taylor Complex Figure	Visual memory	Yes, direction estimation
				Surface Development Test	Mental rotation / spatial visualization	No
				Card Rotations Test	Mental rotation	No
Pazzaglia & DeBeni (2001)	46 (19m, 27f)	NH	Indoor route recall, wayfinding qnr	VMRT	Mental rotation	Yes, questionnaire.
				MPFB		No
Uc et al (2004a)	32 (20m, 12f)	Stroke	Driving along a route according to a set of verbal directions learned to criterion before commencing journey.	RAVLT	Verbal learning & memory	Yes
		NH		Rey Complex Figure Test	Visuo-spatial memory	Yes
				BVRT	Visuo-spatial memory	Yes
	104 (50m, 54f)			COWAT	Verbal fluency / executive function	No
				Trail Making-B	Non verbal executive function	No
				Block design	Visuo-spatial ability	Yes
Uc et al (2004b)	32 (27m, 5f)	MDAT	Driving along a route according to a set of verbal directions learned to criterion before commencing journey.	RAVLT	Verbal learning & memory	Yes
				Rey Complex Figure Test	Visuo-spatial memory	Yes
		NH		BVRT	Visuo-spatial memory	Yes
	136 (67m, 69f)			COWAT	Verbal fluency / executive function	Yes
				Trail Making-B	Non verbal executive function	Yes
				Block design	Visuo-spatial ability	Yes

BVRT = Benton Visual Retention Test; COWAT = Controlled Oral Word Association Test; CTRMT = Camden Topographical Recognition Memory Test; CVLT = California Verbal Learning Test; DSMT = Digit Symbol Modalities Test; GZSO Test = Guilford-Zimmerman Spatial Orientation Test; MDAT = Mild Alzheimer's Dementia; MPFB = Minnesota Paper Form Board; NH = Neurologically healthy; PMA = Primary Mental Abilities; qnr = questionnaire; VMRT = Vanderberg Mental Rotation Test; Vocab = vocabulary.

9.1.2 Visual Memory

Visual memory has been defined as 'the storage of information transmitted through the visual system', or, more specifically, 'a code by which visual perceptions are inscribed and retrieved from memory in the form of images or sequences of images' (Magnussen, 2001, p16264).

Several studies have found correlations between tests of visual memory and performance on wayfinding tasks. Visual memory, as assessed by accuracy of recall of a complex geometric figure, has been shown to correlate with performance on various wayfinding tasks: Nadolne and Stringer (2001) found that complex figure recall correlated with ability to estimate the directions in which landmarks were situated along a recently learned indoor route around a hospital, in a sample of participants with stroke; Moffat et al. (2001) found that it correlated with navigation ability in a VR maze in a sample of participants with no neurological impairment (Moffat et al., 2001); and Uc et al. (2004a; 2004b) found, in a sample of people with stroke and another sample with early Alzheimer's dementia, that it correlated with ability to drive accurately along a real world route recalled from a set of memorized verbal directions. Nadolne and Stringer (2001), however, failed to find any correlation between visual memory and recall of a route around a hospital, with a sample of people with ABI. It is possible that this is a result of differences between the wayfinding task used in their study and those used in the studies of Moffat et al. (2001) and Uc et al. (2004a, 2004b). The relationship between visual memory and route learning in the study of Nadolne and Stringer may have been reduced or eliminated, for example, because their task placed less demand on visual memory. Indoor wayfinding along corridor systems has been hypothesised to be a task particularly amenable to dead reckoning (Cornell et al., 2003), which may have reduced the

extent to which visual memory was required. The fact that the task was relatively simple, with only nine decision points, could conceivably have led to some participants relying upon verbal working memory to rehearse and learn the route as a sequence of commands, which would also minimize the effect of visual memory ability. Unfortunately it is not possible to test this possibility as no measure of verbal ability was included in the study of Nadolne and Stringer (2001). The fact that participants were near ceiling level on the route-learning task, with mean recall percentage scores of between 88 and 97% may also have been a factor.

In fact route complexity has also been found to be a factor in relation to the importance of visuo-spatial skills. Cutmore et al. (2000) found that participants who scored high on visuo-spatial ability[1] were significantly superior on maze navigation than those with low visuo-spatial scores only under the most challenging learning conditions. It is conceivable that visual memory may, similarly, predict wayfinding performance only in sufficiently complex tasks, perhaps because simpler tasks can be completed relatively successfully via various techniques, whereas some use of visual memory is a prerequisite for very difficult tasks. However, it is also worth noting that the maze tasks of Cutmore et al. (2000) that did differentiate between people high and low on visuo-spatial could be classed not only as more challenging than the tasks on which participants performed equally, but also as less realistic. Learning a route forwards through the maze was equally well done by all participants, while learning to reverse a route through the maze and completing the maze based on slides of static views of the maze (rather than dynamic information) were better-performed by those high on

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[1] Visuo-spatial score was calculated by subtracting a 'verbal-sequential' ability score based on the Picture Arrangement subtest from a 'visuo-spatial' score based on the Block Design subtest of the WAIS-R (Wechsler, 1981).

visuo-spatial ability. Similarly, the Nadolne and Stringer (2001) task of learning routes through a hospital is very ecologically valid, whereas the Moffat et al. (2001) maze learning task is less so, suggesting that the more ecologically valid an environment, the less likely visuo-spatial skill or visual memory performance are to predict performance. However, the fact that performance on the task used by Uc et al. (2004a,b), set in the real world involving recall of straightforward routes, did correlate with visual memory contradicts this theory, suggesting that complexity may be more relevant than ecological validity.

Although there is some inconsistency in findings of relationships between visual memory and wayfinding performance, there is certainly an indication that is related to wayfinding ability under some circumstances. The present study, therefore, includes a measure of visual memory. The three studies discussed above employed slightly different complex figure tests; the Taylor Complex Figure (Tombaugh et al., 1992, in Nadolne & Stringer, 2001), the Rey-Osterreith Complex Figure (Rey, 1941; Osterreith, 1944, in Uc et al., 2004a, 2004b), and the Benton Visual Retention Test (Benton, 1974, in Moffat et al., 2001). The present study utilises the Rey-Osterreith Complex Figure, as it is the one the most commonly used clinically in the UK (Riley, 2004, personal communication).

9.1.3 Visuospatial Ability

Visuo-spatial ability refers to the 'capacity to perceive and manipulate objects in space' (Kuelz, Hohagen & Voderholzer, 2004, p209). As mentioned above, rather than looking for correlations between psychometric test scores and performance on wayfinding tasks, Cutmore et al. (2000) divided participants into high and low visuo-spatial ability categories based on

their performance on the block design subtest of the WAIS-R (Wechsler, 1981), and found that those in the high category were better at the more complex maze tasks involving reversing a route and solving the maze based upon static visual cues rather than streaming information. They also found that people who were good on the block design test were better at estimating Euclidean distances between points along the maze. It seems that tasks involving manipulation of spatial information, rather than simple recall of a forward route sequence, are particularly likely to be related to visuo-spatial skill. However, there is also evidence to suggest that straightforward route learning can also be influenced by visuo-spatial skill. Uc and colleagues found correlations between scores on the block design test (WAIS-R, 1981) and performance on a real world outdoor route following task in samples of participants with stroke (Uc et al., 2004a) and early Alzheimer's dementia (Uc et al., 2004b). In a sample of participants without memory impairment, Nori, Grandicelli & Giusberti (2006) also found that people high on visuo-spatial ability (classified according to scores summated across a range of standardized and non-standardized neuropsychological tests) performed better in a real-world test of route learning than those with poor visuo-spatial ability Using a similar battery of standardized and novel tests to create a composite score for visuo-spatial ability, however, Fenner, Heathcote and Jerrams-Smith (2000) found a correlation with real-world route learning performance only for a sub-set of their sample. They tested neurologically healthy children aged between 5 and 6 and between 9 and 10 years, and found that only the younger group's visuo-spatial scores correlated with real world route learning performance. However, this is quite possibly attributable to several methodological issues such as non-standardized tests being included in the battery (with potential age effects uncontrolled for) and a small sample size of just 10 participants in each age group resulting in insufficient

power to detect an effect. The fact that the previously cited studies with adults found correlations between visuo-spatial performance and route-learning in adults supports this possibility. Performance on the present study's route learning task, set in a complex outdoor (virtual) environment, therefore, was expected to correlate with visuo-spatial ability. The block design subtest of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) is included to test this prediction[1].

A specific visuo-spatial skill that several studies have shown to correlate with wayfinding performance, is mental rotation ability (Fields & Shelton, 2006; Moffat et al., 1998; Moffat et al., 2001; Pazzaglia & De Beni, 2001), although not all studies have observed the correlation (Nadolne & Stringer, 2001). The majority of mental rotation tests involve imagining objects moving in allocentric space, that is, rotation of objects within a spatial frame of reference external to oneself, e.g. the Vandenberg Mental Rotation Test (Vandenberg & Kuse, 1978), and the Card Rotation Test (Ekstrom et al., 1976). However, there are also a small number of tests that assess egocentric mental rotation, or the imagined rotation of one's own body and associated change of perspective. One example of egocentric mental rotation is the Standardized Road Map Test of Direction Sense (Money et al., 1965), which requires judgments about the directions of turns one would need to make when traveling along a route marked out on a schematic map. Another mental rotation test that can be done by imagining oneself moving within an environment is the Guilford Zimmerman Spatial Orientation Test (Guilford & Zimmerman, 1948), in which one makes judgments about the changing positions

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[1] Although previous studies have mostly used the block design subtest from the WAIS-R (Wechsler, 1981), the present study used the WASI (Wechsler, 1999), because a number of participants had already completed this version of the block design as part of routine neuropsychological assessments.

of a boat's hull from viewing sketches of the location of landmarks such as buoys and the shoreline. There is evidence to suggest that mental rotations in allocentric and egocentric frames of reference (also defined as 'spatial visualisation' and 'spatial orientation', respectively; Hegarty and Waller, 2003) involve dissociable cognitive mechanisms and are subserved by different cortical areas (Tomasino & Rumiati, 2004). It would seem likely that allocentric mental rotation ability might be related to the effectiveness with which participants are able to use a survey perspective, while egocentric rotation might correlate with ability to learn a route from a first-person perspective. Moffat et al. (1998) found performance on three different tests of mental rotation (shown in table 10); to correlate with performance on a simple VR maze task, and Fields and Shelton (2006) found that tests of mental rotation and perspective taking predicted performance on a direction estimation test within a VR simulation of a park environment (see table 10). Nadolne & Stringer (2001), however, failed to find a correlation performance on the Card Rotations Test (Ekstrom et al., 1976) and the Surface Development Test (Ekstrom et al., 1976) and performance on their indoor route-learning task. As discussed earlier, this could again be attributable to ceiling effects, with performance on the route-learning task typically averaging over 90%, or it could be because they only tested allocentric mental rotation skills, whereas route-learning might be intuitively expected to be more closely related to egocentric mental rotation.

In summary, complexity of the task and the degree to which the task involves manipulation of spatial information seems to be related to the requirement for visuo-spatial ability. As the present study involved route learning, a test of mental rotation from an egocentric perspective (or a 'perspective taking' test, Hegarty & Waller, 2004) was deemed most appropriate for

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inclusion, particularly as Nadolne and Stringer were unable to replicate the relationship between allocentric mental rotation and performance on a route learning task from a first-person perspective. The Money Road Map Test (Money et al., 1965) was selected as the most well-validated test of egocentric mental rotation. While there are a number of new tests designed to assess egocentric mental rotation in a more thorough way (e.g. the Object Perspective Taking Test; Hegarty & Waller, 2004), they are generally lacking standardization data from samples of participants with ABI. Furthermore, the Money Road Map Test is relatively easy to administer (and comprehend), and can be completed in a short space of time.

9.1.4 Executive function

Most studies examining neuropsychological tests related to wayfinding focus on tests of visuo-spatial ability and visual memory (e.g. Fields & Shelton, 2006; Nadolne & Stringer, 2001); and some include measures of verbal memory (Fields & Shelton, 2006; Moffat et al., 2001); but few measure executive function. A possible role for executive function in route learning is suggested, however, by findings from Uc et al. (2004b) of correlations between route-recall in a real world driving task and performance on two tests of executive function; the Trail Making test (Reitan et al., 1992) and the Controlled Oral Word Association Test (COWAT) (Benton & Hamsher, 1976), in a sample of participants with early Alzheimer's dementia. They failed to find these correlations with a sample of people with stroke on the same task, however (Uc et al., 2004a). Because the task used involved memorizing a short set of verbal directions and then following them in a real world environment, it is possible that effects of executive function may have been minimal and gone undetected in the relatively

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small sample of 32 people. A larger effect for executive function might be expected in the route-learning task used by the present series of studies (despite no larger a sample), because it involves the participant more in observing and encoding the route during learning trials, potentially drawing more heavily upon executive skills. Because the COWAT has also been shown to correlate with performance in a VR maze task with participants with no neurological impairment (Moffat et al., 1998), and it is a quick and easily administered task, the COWAT was selected as a measure of executive function for the present study.

The COWAT is a verbal fluency task that is thought to be sensitive to prefrontal cortex functioning generally (e.g. Gladsjo et al., 1999), and there are several conceivable ways in which prefrontal (or executive) abilities could impact upon route learning. For example, executive function may influence a person's ability to use wayfinding strategies flexibly, an attribute that is, anecdotally, associated with good wayfinders (Kato & Takeuchi, 2003). Alternatively (or additionally), it may be because people with better executive functioning are more able to sustain focused attention throughout learning trials, perhaps encoding more stimuli or more relevant stimuli than people with poor executive functioning.

9.1.5 Verbal skills

Tests of verbal skills are rarely included in neuropsychological test batteries administered in wayfinding studies, and studies that have tested language have largely failed to find it predictive of wayfinding ability. Moffat et al. (2001) failed to find a relationship between virtual maze navigation and performance on either the Primary mental abilities test (DeFries et al., 1974, in Moffat et al., 2001), a test of knowledge of word meanings, or on the

'similarities' subtest of the WAIS-R (Wechsler, 1981), a test of ability to make judgments about synonyms. Fields and Shelton (2006) found no correlation between comprehension of read material and direction estimates in the VR park environment. However, Moffat et al. (1998) did find a relationship for female participants between scores on the Advanced Vocabulary Test (Ekstrom et al., 1976, in Moffat et al., 1998) and maze navigation performance.

It is possible that verbal ability would be more predictive of wayfinding when measured by recall of routes in a naturalistic environment, as complex real world routes contain more distinctive features that could potentially be coded verbally than the maze environments used by Moffat et al. (1998, 2001) do, for example. Additionally, it is possible that verbal ability may become a more important predictor of wayfinding ability in participants with ABI when there is impairment in visuo-spatial performance, as they may need to compensate by using verbal skills. Nadolne and Stringer (2001) and Uc et al. (2004a) did not include a measure of verbal ability in their studies of route learning with people with ABI, so the present study includes the vocabulary subtest of the WASI (Wechsler, 1999), a test of verbal knowledge.

9.1.6 Verbal Memory

Correlations between performance on wayfinding and list learning tasks suggest a role for verbal memory in route learning. Moffat et al. (2001) found correlations between performance on their VR maze task and scores on the California Verbal Learning Test (Delis et al., 1987) and Uc et al. (2004a,b) found correlations between performance on the Rey Auditory Verbal Learning Test (RAVLT; Rey, 1964) and route recall in a real world driving task by

participants with stroke and early Alzheimer's dementia. However, Maguire et al. (2003) found no correlation between performance on the Adult Mental Information Processing Battery (AMIPB) story recall subtest (Coughlan & Hollows, 1985) and the ability to navigate between locations in a virtual town. It is possible that verbal memory is more closely related to route learning performance than to knowledge about the layout of an environment, as the studies in which a correlation was observed both assessed ability to follow a route of some kind, whereas those failing to find a correlation both assessed survey knowledge of the environment. Because the present study assessed route learning, it was considered likely that verbal memory performance would predict recall, and the list-learning subtest of the AMIPB (Coughlan & Hollows, 1985), a test similar to those employed by Moffat et al. (2001) and Uc et al. (2004a;b), but somewhat more widely used clinically, was used to assess it.

9.1.7 Working Memory

Creating a working memory load during route learning, by asking participants to recite verbal sequences or tap out spatial sequences on blocks, has been shown to have a negative impact upon recall of routes learned both via a slideshow (Allen & Willenborg, 1998; Garden et al., 2002) and in the real world (Garden et al., 2002). This suggests that both verbal working memory and visuo-spatial working memory are involved in route learning. This does not necessarily indicate that individual variations in working memory would predict route-learning ability, but a few studies have directly assessed this possibility. Moffat et al. (2001) found that backwards digit span, a measure of verbal working memory, was correlated with time taken to complete a VR maze, and Fields and Shelton (2006) found a correlation between spatial span (a measure of visuo-spatial working memory) and direction estimations

within their VR park environment, but failed to find a correlation between performance on the direction estimation test and a test of word span (i.e. the number of words that could be held in working memory). The fact that the Moffat et al. (2001) study implicated verbal working memory but the Fields and Shelton (2006) study did not could be related to the difference in outcome measures, with the former measuring route learning and the latter assessing judgments about the configuration of an environment. Intuitively, verbal working memory might be used in the learning of a route (e.g. for memorising a series of turns) more so than in the learning of the layout of an environment. As the present study assessed route learning, it was likely that the task might involve using working memory and digit span was considered most likely to correlate with performance. A measure of visuo-spatial working memory, the spatial span subtest of the Wechsler Memory Scale (Wechsler, 1998) was also administered, however, as Garden et al. (2002) and Allen and Willenborg (1998) both found that route learning was impaired by creating a load on visuo-spatial *or* verbal working memory.

9.1.8 The relationship between cognitive deficits, learning technique and strategy use.

While degree of memory impairment in general is, logically, likely to correlate inversely with route learning performance, it may have a more specific effect upon differential performance under various learning conditions. For example, there is some evidence to suggest that the more severely impaired a person's explicit memory, the more benefit they will derive from errorless learning compared with errorful learning (Evans et al., 2000; Riley et al., 2004). The present study will examine whether, in a practical route-learning task, there is an increased advantage of errorless over errorful learning for participants with more severe memory impairment.

The advantage derived from using errorless learning in conjunction with the naturalistic techniques of cognitive mapping and landmark memorization may also be related to the degree of memory impairment. Riley at al (2004) suggest that more severely impaired participants derive greater benefit from the less active but more thoroughly error free technique of errorless learning than the method of vanishing cues, while less impaired participants show the reverse pattern. This is because those with more severe memory impairment rely on implicit memory which requires the minimization of errors and their explicit memory is so impaired that it does not benefit from the richer encoding offered by vanishing cues (Riley et al., 2004). In the case of route learning, therefore, it may be that participants with high scores on memory tests may demonstrate a greater advantage of the naturalistic strategy conditions over the simple errorless conditions, whereas participants with poorer memories may not benefit from the extra strategies. If the greater advantage of errorless learning over the method of vanishing cues for people with greater memory impairment is simply because they are particularly sensitive to errors (which are slightly more likely with the method of vanishing cues), the present study may not show the same effect, as all conditions are fully errorless. I.e. our more active conditions are not more active at the expense of being less errorless. Finally, the relative merits of different naturalistic strategies for route learning may vary according to individual cognitive deficits. This has been demonstrated to some extent in non-clinical populations. Pazzaglia and De Beni (2001) found that people who preferred using survey strategies (i.e. techniques like cognitive mapping) scored more highly on the Vandenberg Mental Rotation Test (Vandenberg & Kuse, 1978), than those who preferred landmark based strategies. It is possible, therefore, that people who

score highly on tests of visuo-spatial ability like the mental rotation test used in the present study will be more comfortable in the cognitive mapping condition and perform better in it than in the landmark condition. On the other hand, it is possible that people whose visuo-spatial ability is poor and so cannot use cognitive mapping will derive benefit from the landmark condition.

9.1.9 Summary

In summary, there are a range of cognitive deficits that may have an impact on route learning performance but the degree to which these affect performance may relate to the complexity of the task, the degree to which it involves the use of visuospatial ability and the degree to which is possible to verbalise the task. In addition, the learning situation (i.e. errorless or errorful learning) may differentially affect those with good and poor memory ability. Finally, success in using a specific strategy may also be related to residual cognitive skills.

The present study, therefore, has three aims. The first is to assess the relationships between route learning performance and scores on: measures of verbal ability and verbal memory; visuo-spatial ability and visuo-spatial memory; executive function; and working memory. No previous study has used such an extensive neuropsychological battery to predict performance on route learning in this way. In Chapter 7 it was shown that errorless learning was the most effective strategy for route learning (and in the present series of studies, this condition also provided the largest sample size) and cognitive deficits were used to predict performance in the errorless condition only.

Secondly, the study aimed to explore the relationship between cognitive deficit and benefits of errorful or errorless learning, with a tentative prediction that there will be a positive correlation between the degree of benefit afforded by errorless over errorful learning and severity of memory impairment.

Thirdly, a much more tentative aim was to explore the relationship between cognitive deficit and the benefit derived from conditions where errorless learning is supplemented by landmarks or a cognitive mapping strategy. Previous work might suggest that those with greater impairment would benefit less from the use of additional strategies.

9.2 Method

9.2.1 Participants

A total of 38 participants completed the present study; 20 of these had completed study 3, and a different set of 18 participants had completed study 4. Demographic details for these participants are presented in the respective chapters, and mean age, time since injury, and list learning scores from the AMLPB (Coughlan & Hollows, 1985) are summarized in table 10, along with a breakdown of injury aetiologies. Of the eight participants classified as 'other', two had acquired their injury through cortical cysts, five through tumour, and one through drug use. The sample for the present study (study 5) is comprised of all those participants who took part in study three and all those who took part in study four. For participants in study five, therefore, everyone has a score for learning under errorless conditions, but only half the sample (i.e those participants who did study 3) has scores for errorful learning, and only the other half the sample (i.e. those participants who did study 4) has scores for the landmark strategy and cognitive mapping strategy conditions.

Table 11: Summary of participant characteristics

Took part in study	Number of participants	Mean (SD) age	Mean (SD) list learning t score	Mean (SD) time since injury (months)	Injury aetiology (n)		
					TBI*	Vascular	Other
3 & 5	20	42.50 (12.03)	24.06 (10.23)	115.95 (104.73)	8	6	6
4 & 5	18	46.78 (13.65)	28.92 (13.75)	124.94 (134.58)	12	4	2
5	38	44.53 (12.83)	26.42 (12.16)	120.21 (118.21)	20	10	8

*Traumatic brain injury

A full set of neuropsychological test scores for the battery described below is available for 32 out of the 37 participants. Of the five participants missing neuropsychological test data, one participant moved away before testing could be completed, one participant did not wish to complete the tests, one participant completed all the tests with the exception of the Block Design and Rey-Osterrieth Complex Figure (see below for descriptions), which he was prevented from doing by severe motor impairment, one participant completed all tests with the exception of the vocabulary test, as he left the rehabilitation centre before this test could be administered, and the final participant is missing scores for the Money road map test, the Rey complex figure, the vocabulary test and the COWAT because he was unavailable across several sessions towards the end of data collection.

9.2.2 *Apparatus and materials*

The route learning scores analyzed in this study are taken from patient studies 3 and 4 (chapters 7 and 8), so the apparatus and routes used are exactly as described in the previous two chapters (see sections 7.2.3 & 8.2.3).

9.2.2.1 Standardized Road Map Test of Direction Sense (Money, Alexander & Walker, 1965):

This is a test of egocentric mental rotation or 'spatial orientation' (Hegarty & Waller, 2003) that measures the ability to make left versus right judgments about the turns required to follow a route marked out on a schematic road map, and it must be completed without rotating the map or the head or body. The experimenter traced the marked route while participants called out their left / right decision at each turn, noting down the responses for later scoring.

There were 32 decision points in total Standardization data are available for neurologically unimpaired samples and for participants with ABI (Money et al., 1965; Vingerhoets, Lannoo & Bauwens, 1996). No age-scaled scores are available for this test, as there is little evidence for an age-related decline in average performance (Lezak, 1995; Vingerhoets et al., 1996). This test is commonly referred to as the 'Money Road Map Test' (e.g. Vingerhoets et al., 1996).

9.2.2.2 Controlled Oral Word Association Test (Benton and Hamsher, 1976):

This test of verbal fluency and prefrontal cortex function (Lezak, 1995) involves the participant generating as many words as possible beginning with the letters F, A and S in turn, with a one minute period allocated for each letter. Names, numbers, and stem repetitions (e.g. fast, faster, fastest) are not permissible, and participants are told this pre-test. Test-retest reliability is .74 (Ruff et al., 1996). This test has been used in several studies with participants with ABI (see Lezak, 1995). Level of education is a significant influence on task performance, so participants' scores are adjusted according to the formula provided in the manual (Benton & Hamsher, 1976), and can then be converted to age-scaled t-scores.

9.2.2.3 Block Design subtest (Wechsler Abbreviated Scale of Intelligence (WASI); Wechsler, 1999):

This test of visuo-spatial ability involves the manipulation of four or nine blocks, each of which is coloured completely white on two faces and completely red on two faces, with the other two faces split in half diagonally with one half red and the other white. Patterns are displayed on a stimulus card, which participants must reproduce using the blocks. The

patterns increase in difficulty, and participants start by completing four-block patterns before moving onto nine blocks after successful completion of the simpler designs. The split-half reliability coefficient for this test is .92. Normative data are available for this test, and raw scores are converted to age-scaled t-scores.

9.2.2.4 Vocabulary subtest (WASI; Wechsler, 1999):

This test, in which participants are required to provide definitions for 40 words of increasing difficulty, measures 'both the extent of recall vocabulary and the effectiveness of speaking vocabulary' (Lezak, 1995, p.539). The average inter-rater reliability coefficient of this test is .98, and the test-retest reliability is between .90 and .98. Normative data are available for this test, and data are converted to age-scaled t-scores (Wechsler, 1999).

9.2.2.5 Rey-Osterreith Complex Figure Test (Rey, 1941, Osterreith, 1944):

In this test of visual memory and visuospatial ability, participants copy an image of a complex figure, and are then reproduce the image from memory immediately, and then after 30 minutes' delay. The inter-scorer reliability coefficient of this test is between .91 and .98, and the test-retest reliability, using alternate forms, is between .60 and .76 (Lezak, 1995). Normative data are available for this test (Rey, 1941, Osterreith, 1944), and participants' raw scores are converted to age-scaled t-scores.

9.2.2.6 List Learning subtest of the Adult Memory and Information Processing Battery (Coughlan & Hollows, 1985):

This test of verbal memory involves learning a list of fifteen words repeated across five trials. On each trial, the experimenter reads out the list of words and the participant then calls out as many of the words as possible, in any order. Upon completion of the five trials a novel list of fifteen is presented once, and participants recall as many items as possible. Following this distraction, participants are asked to recall as many words as possible from the original list. The reliability coefficient for trials 1-5 test is .77, and for the post-distracter-list trial (A6), it is .73. Raw scores are age scaled before being converted to t-scores.

9.2.2.7 Digit Span subtest of the Wechsler Memory Scale-III (Wechsler, 1998)

This test of verbal working memory consists of a forwards and a backwards condition. Digit span forwards involves repeating, in order, sequences of numbers called out (at a rate of one digit per second) by the experimenter. Strings increase in length every two trials, until a participant fails to correctly recall two strings of a given length. Digit span backwards involves repeating strings of digits in reverse order from the order in which they are presented. This test has a reliability coefficient of .85 to .92, and the total score (created by summing the scores for strings recalled forwards and backwards) can be converted into an age-scaled t-score.

9.2.2.8 Spatial Span subtest of the Wechsler Memory Scale-III (Wechsler, 1998).

This test of visuo-spatial working memory involves the use of a board with ten blocks affixed in an irregular pattern, which the experimenter taps in sequences that the participant must

repeat, at first, in the same order. The sequences increase in length every two trials until the participant fails two trials of the same length. A new set of sequences are then tapped out, which the participant must repeat in reverse order, until they fail to recall two sequences of the same length. This test has a reliability coefficient of .79, and the scores for the forwards span and backwards span can, individually, be converted to age scaled t-scores.

9.2.2.9 Star Cancellation Test (Wilson, Cockburn & Halligan, 1987).

This subtest of the Behavioural Inattention test (Wilson et al., 1987) assesses visuospatial neglect. Participants are presented with a page filled with a 'jumble of words, letters and stars' (Lezak, 1995, p.389), and are required to cross out all of the small stars on the page. Missing more than two stars is an indication of potential inattention. Scores on this test were not included in the analyses described. It was used purely to screen out participants with neglect or hemi-inattention, as it was considered probable that such impairment may impact severely on ability to learn routes presented on a television screen. This test has been demonstrated to be clinically sensitive, identifying 100% of participants (n=30) with inattention (Halligan, Marshall & Wade, 1989, in Lezak, 1995), and is well correlated with other tests of inattention (correlation coefficient between .65 and .80).

9.2.3 Procedure

The route learning tasks were exactly as described in Chapters 7 & 8, as the present study uses the route learning scores from those studies. Participants completed their two to three route learning assessments on separate occasions, usually at the same time each week for three consecutive weeks. At each testing session, several psychometric tests were

administered. There was no set order in which tests were given, except that where participants appeared to become demoralized by poor performance on a particular test, effort was made to follow it with a test tapping a different cognitive skill in order to minimize feelings of frustration.

9.3 Results

9.3.1 Summary of Scores

Mean and standard deviations for scores on all tests for the whole sample are provided in table 12

Table 12: Mean scores on route learning and neuropsychological tests

Test		Score information			
		Mean	N	S.D.	Range
Number of route recall errors (out of max.14)	After errorless learning	3.42	38	1.84	1-8
	After errorful learning	4.65	20	2.35	2-9
	After errorless learning plus landmark use	3.39	18	2.28	0-8
	After errorless learning plus cognitive mapping	3.44	18	2.01	0-7
List learning (A1-A5)*		26.61	37	11.74	6-49
List learning (A6)*		27.31	37	14.39	4-81
Vocabulary*		42.43	35	12.94	20-73
COWAT*†		39.87	36	11.78	27-73
Rey Complex Figure (immediate recall)*		31.45	33	17.30	0-65
Rey Complex Figure (delayed recall)*		27.67	33	20.86	0-71
Block design**		45.50	34	11.15	20-64
Spatial span forwards**		7.75	36	2.63	2-14
Spatial span backwards**		8.69	36	2.20	4-15
Digit span total**		7.59	37	2.05	3-13
Money Road Map (score out of 32)		26.11	36	5.68	12-32

*Age-scaled t-scores; **age-scaled Wechsler subtest scores; †age & educational level scaled scores

9.3.2 Correlations between neuropsychological test scores and route learning; and results of regression analysis

Prior to regression analysis and in order to establish which cognitive skills were correlated with route learning performance, Pearson's correlation coefficients were carried out between

all neuropsychological test variables and number of errors in all the four possible learning conditions (see table 13).

Table 13. Pearson correlations between neuropsychological tests scores & route learning performance

Neuropsychological Tests	Errors under route learning conditions			
	Errorless	Errorful	EL + map	EL + landmark
	(n= 34–37)	(n=17-20)	(n=17-18)	(n=17-18)
Rey (immediate recall)	-.07	-.25	-.04	.05
Rey (delayed recall)	-.18	-.23	-.24	-.17
List Learning	-.48**	-.39	.02	-.17
Vocabulary	-.38*	.21	.10	.05
Block Design	-.23	-.05	-.03	.23
COWAT	-.31	.33	.34	.40
Digit Span	-.27	.23	-.06	.05
Spatial Span (forwards)	.10	.23	-.14	-.22
Spatial Span (backwards)	-.14	-.06	-.33	-.22
Money	-.23	-.07	.06	-.15

*p = .023, **p <0.0005

The number of wrong turns taken in the errorless condition correlated inversely with list-learning z- scores and vocabulary t- scores. There were no other significant correlations (see table 13) and therefore only these two variables were entered into a regression. In order to determine how much of the variance in route learning performance they could predict.

A significant regression was obtained, ($F_{(2,31)}$ =4.68, p= .017) using forced entry and showed that these two variables accounted for 18% of the variance in errors made on the route, (adjusted R^2 = .18) List learning made the most important contribution to the model (see table 14).

Table 14: Multiple regression model for errorless learning test trial errors.

Regression Model	Standardized Coefficients	t	Significance
	Beta		
Constant		2.13	.04
List learning	-.31	-.16	.13
Vocabulary	-.22	-.11	.29

Dependent variable: number of errors made on errorless test trial.

There were no significant correlations between neuropsychological test scores and performance on any of the other three route learning conditions (errorful learning, errorless learning with landmarks, and errorless learning with cognitive mapping). A post-hoc power analysis was carried out to determine whether the lack of correlations in these conditions, in which sample sizes ranged from 17 to 20 (depending on the neuropsychological test scores available) compared with sample sizes of 34 to 37 in the errorless condition, could be an artefact of low power. The analysis revealed that the correlations between scores in the errorful, errorless plus landmark and errorless plus cognitive mapping conditions did suffer from low power. There was only good power (.80 and above) to detect correlations of a magnitude of .6 and over for these conditions. Power to detect small relationships of around .3 was only at approximately 25%. Because of the larger sample sizes for the errorless condition,

there was good power (.80 and above) to detect correlations of approximately .43 magnitudes and above.

9.3.3 Correlations between neuropsychological test scores and relative benefit derived from specific learning conditions

In order to explore whether patterns of cognitive impairment would impact upon the relative merit of errorful vs errorless learning, a discrepancy score was calculated by subtracting the number of errors made under errorless condition from the number of errors made under the errorful condition. This therefore represented the degree of advantage of the errorless condition over the errorful condition. The mean discrepancy score across subjects was 1.25 (SD 2.12) suggesting an overall advantage of errorless learning, as found in Chapter 7. This was then correlated with cognitive test scores and showed that those with better executive skills as measured by the COWAT benefited more from errorless learning (table 15).

Similarly, by subtracting errors for the 'EL+map' or the 'EL + landmark' condition from the simple EL condition, discrepancy scores were derived representing the advantage of the map or the landmark condition over errorless learning alone. These discrepancies were then correlated with each psychometric test variable (see table 15). The advantage of the landmark condition over simple errorless learning correlated inversely with vocabulary and COWAT test scores. The advantage of the cognitive mapping condition over errorless learning alone correlated inversely with list learning, vocabulary scores and COWAT scores.

Finally, the relative advantage of maps over landmarks was calculated by subtracting errors in the former from errors in the latter condition. This did not correlate with any of the psychometric test variables (table 15).

Table 15: Pearson correlations between Neuropsychological test scores and differential benefit derived from learning conditions

	Differential benefits from learning conditions			
Neuropsychological Tests	EL advantage over EF (n= 18-19)	EL + map advantage over EL (n=17-19)	EL + landmark advantage over EL (n=17-19)	EL + map advantage over EL + landmarks (n=17-19)
Rey (immediate recall)	-.41	-.12	-.18	.12
Rey (delayed recall)	-.32	-.08	-.11	.06
List Learning	-.16	-.51*	-.30	-.25
Vocabulary	.22	-.61**	-.52*	-.06
Block Design	-.01	-.25	-.45	.35
COWAT	.58**	-.58**	-.61**	.14
Digit Span	.31	-.34	-.39	.13
Spatial Span (forwards)	.13	.17	.24	-.13
Spatial Span (backwards)	.02	.14	.07	.09
Money	.13	-.25	-.06	-.26

*p<.05, **p<.01

9.3.4 Exploratory ANOVAs

The latter correlations suggested relationships in the opposite direction to that expected according to Riley at al (2004), i.e. people with more marked cognitive impairment seem to

benefit more from additional strategies. Thus, exploratory ANOVAs were conducted to gain an initial more in-depth perspective of whether there was any interaction between performance on any of these tests and performance under the different learning/strategy conditions. Whilst these ANOVAs are based on small sample sizes and any conclusions should be treated with caution, they were viewed as potentially valuable for directing future research.

9.3.4.1 Vocabulary

A 2*3 mixed within and between participants ANOVA was carried out to assess the effects of verbal ability (vocabulary test scores) and learning condition on route recall. The between participants factor was verbal ability, with two levels: impaired (2 SD or more below the mean, n=4) and unimpaired (anything superior to 2 SD below the mean, n=13). The within-participants factor was learning condition, with the three levels being EL, EL + landmark, and EL + map. There was no main effect of learning condition or of verbal ability, but there was a significant interaction, shown in figure 8, below (F $_{(2,30)}$ = 4.53, p = 0.02). The number of participants with impaired vocabulary (n=4) is too small to permit post-hoc tests[1], so the analysis is purely exploratory, but it seems to demonstrate that participants who are unimpaired on the vocabulary test are relatively unaffected by the additional strategies used alongside errorless learning, or possibly even perform a little worse with them, whereas those

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[1] NB – The small sample size here may also lead to concern that the effect is an artefact of all participants receiving, by chance, the same order of presentation of conditions (e.g. everyone completing their first condition under errorless conditions, and improving over sessions due to practice rather than any true benefit of the additional strategies). However, the order of presentation was reasonably well counter-balanced across the four people with impaired vocabulary, with simple errorless learning being the first condition completed by one, the last condition completed by one, and the second condition completed by two participants.

people with poor vocabulary derive benefit from either type of strategy, performing at a similar level to people with unimpaired vocabulary when given a strategy.

Figure 8: Mean route recall errors under different learning conditions for participants with and without impaired performance on the vocabulary test.

9.3.4.1 List learning

A 2*3 mixed within and between participants ANOVA was carried out to assess the effects of verbal memory and route learning conditions on route recall. The between participants factor was verbal memory, with two levels: impaired (2 SD or more below the mean, n= 10) and unimpaired (anything superior to 2 SD below the mean, n= 8). The within participants factor was learning condition, with the three levels being EL, EL + landmark, and EL + map. There

was no main effect of learning condition or of verbal memory, but the interaction narrowly missed significance ($F_{(2,32)} = 3.047$, p = 0.061). Although this effect is not significant, figure 9, below, demonstrates a similar pattern of interaction to that observed with vocabulary scores, i.e. participants who are unimpaired on the list learning test are relatively unaffected by the additional strategies used alongside errorless learning, whereas those people with poor list learning derive benefit from either type of strategy. They seem to make fewer errors than with errorless learning alone when using landmarks, although are still slightly worse than participants unimpaired in list learning, and they are performing at a similar level to people with unimpaired verbal memory when given a cognitive mapping strategy.

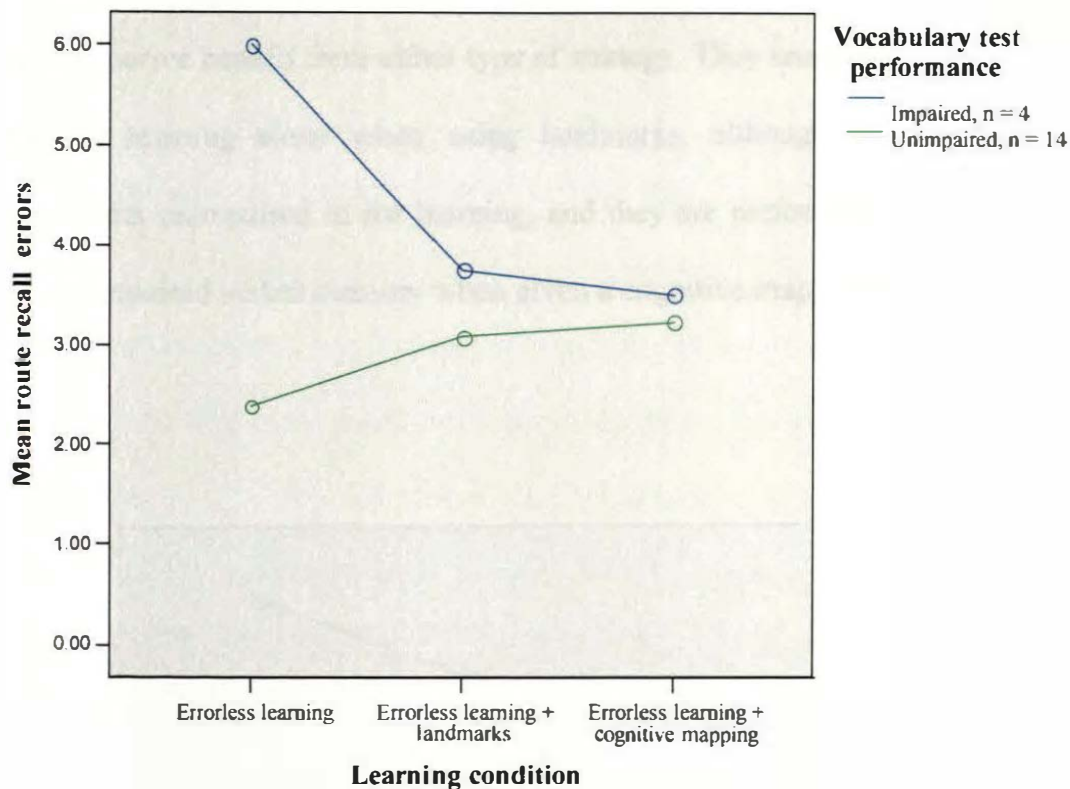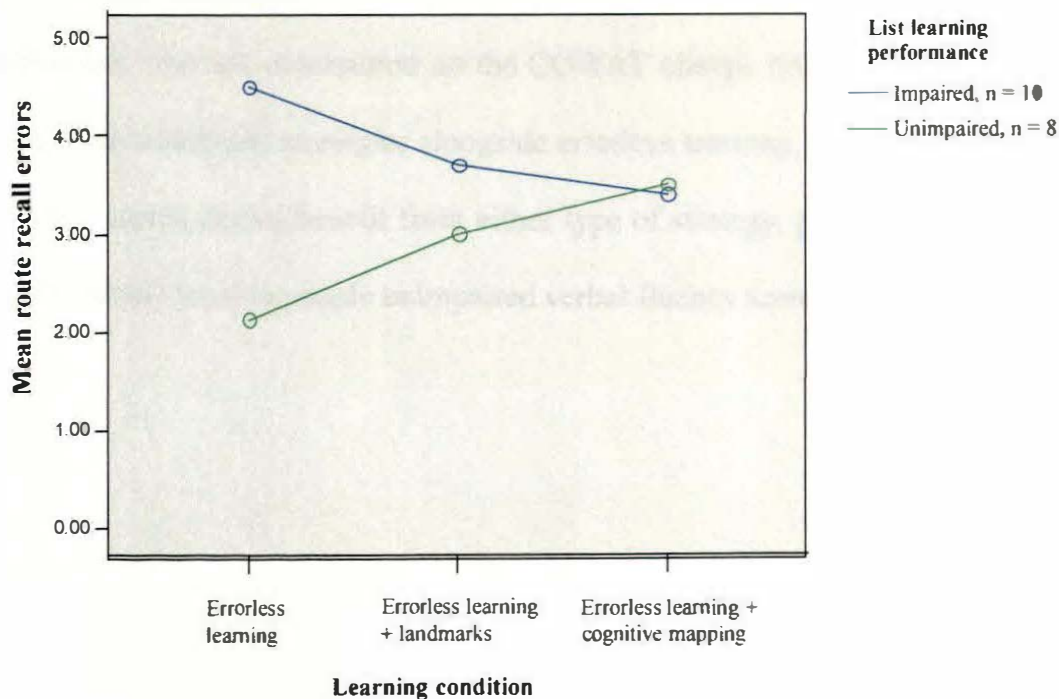**Figure 9:** Mean route recall errors under different learning conditions for participants with and without impaired performance on the list learning test.

9.3.4.2 COWAT

A 2*3 mixed within- and between- participants ANOVA was carried out to assess the effects of verbal fluency and route learning conditions on route recall. The between-participants factor was COWAT performance, with two levels: impaired (2 SD or more below the mean, n = 6) and unimpaired (anything superior to 2 SD below the mean, n = 11). The within participants factor was learning condition, with the three levels being EL, EL + landmark, and EL + map. There was no main effect of learning condition or of COWAT performance, and the interaction was not significant, perhaps as the differences between scores under different conditions are relatively small for both groups (see figure 10). However, figure 10, below, does demonstrate a similar pattern of interaction to that observed with list learning scores, i.e. participants who are unimpaired on the COWAT change little or are actually slightly worse when given additional strategies alongside errorless learning, whereas those people with poor COWAT scores derive benefit from either type of strategy, performing at a similar (or even slightly better) level to people unimpaired verbal fluency scores when given a strategy.
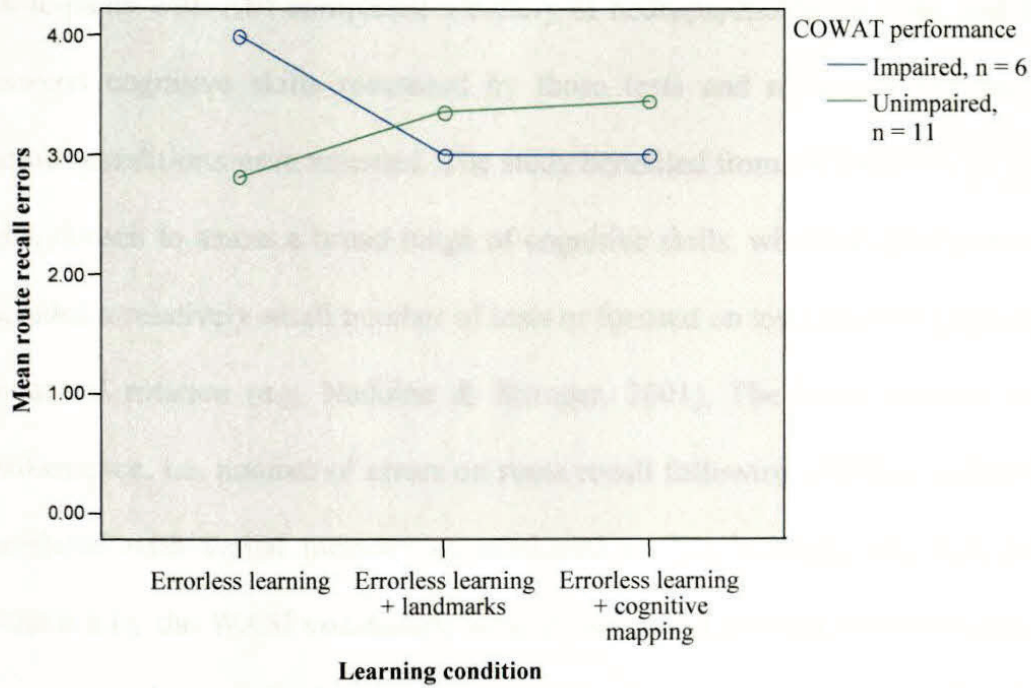
Figure 10: Mean route recall errors under different learning conditions for participants with and without impaired performance on the COWAT

9.4 Discussion

Participants with ABI completed a battery of neuropsychological tests, and the relationships between cognitive skills measured by those tests and route learning performance under various conditions were assessed. The study benefited from the inclusion of a large number of tests, chosen to assess a broad range of cognitive skills, whereas many previous studies have included a relatively small number of tests or focused on tests assessing a specific ability such as mental rotation (e.g. Nadolne & Stringer, 2001). The main measure of route learning performance, i.e. number of errors on route recall following errorless learning, was inversely correlated with verbal memory as measured by list learning, and with verbal ability, as measured by the WASI vocabulary subtest. Both of these factors contributed to the variance in errors made, with list learning being the most important predictor of the two. Scores for route recall when errorless learning was combined with each of the naturalistic strategies of landmark use and cognitive mapping failed to correlate with any of the psychometric test scores.

The advantage of errorless learning over errorful learning correlated with scores on the COWAT, that is, the better a person's verbal fluency, the greater the benefit derived from errorless learning. The degree of benefit derived from learning with landmarks compared with learning in the simple errorless learning condition was correlated inversely with vocabulary scores and with verbal fluency scores. That is, the worse a person's vocabulary or executive functioning, the more benefit they gained from the addition of the landmark strategy. Similarly, there was an inverse correlation between benefit gained in the cognitive

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mapping condition and scores on the vocabulary and COWAT tests, and also with list learning scores. Finally, exploratory ANOVAs suggested that on vocabulary, list learning and verbal fluency, people who were impaired derived some benefit from the additional strategies but people who were unimpaired on these tests derived no benefit or performed slightly less well than under simple errorless learning conditions.

9.4.1 Predictors of route learning in the main errorless learning condition

The fact that list learning predicted route learning performance in the main errorless learning condition is consistent with previous findings of a correlation between verbal memory and wayfinding performance (Moffat et al., 2001; Uc et al., 2004a,b) It suggests that lack of correlation between performance and verbal memory in the studies of Maguire et al. (2003) and Fields and Shelton (2006) may be attributable to the fact that their tasks assessed configurational knowledge of the environment rather than route learning. The fact that vocabulary scores also predicted performance is at odds with the findings of Moffat et al. (2001) of a correlation between verbal skills and wayfinding ability for female participants only, and of Fields and Shelton (2006) who reported no correlation between verbal ability and direction estimations. However, it is consistent with the idea that verbal ability may be more related to route learning than to general processing of spatial relations.

The failure to find correlations between the main route learning measure and scores on any other psychometric tests is somewhat surprising given previous findings. It may be that the tests of visuo-spatial ability and visual memory do not predict performance in the present study because the task can be accomplished via primarily verbal means, as evidenced by the

correlations with list learning and vocabulary scores. It is also possible that the way in which the route-learning task was carried out, with directions called out verbally during learning trials, increased involvement of verbal ability.

9.4.2 Cognitive skills and the relative merit of errorless versus errorful conditions

Executive function, as measured by the COWAT, was related to the benefit derived from errorless learning over errorful learning, that is, people with better executive function benefited more from learning without errors than those with poor executive function. Conversely, those who gained less advantage from the errorless strategy had more impaired executive skills. While this may seem, initially, inconsistent with predictions that more impaired participants would benefit more from simple errorless conditions, there is a possible explanation. Riley et al. (2004) observed that errorless learning is more beneficial than the method of vanishing cues for people with more severe *memory* impairment, or under more complex conditions, because the benefits of complete error prevention in these cases outweigh the benefits of more active involvement generated by the method of vanishing cues. Here we have a situation where the benefits of active involvement (as in the landmark or map strategy) may outweigh the benefits of simple errorless learning when people have poor executive skills. This may be because they find it more difficult to maintain attention and interest on the learning trials in the errorless condition and so derive slightly less benefit from it. This highlights the importance of considering individual cognitive differences in a clinical setting when choosing the learning strategy. Although errorless learning may offer a general advantage over errorful learning when participants' results are grouped (as shown in Chapter 7), its disadvantages for people with executive problems may need to be considered. This was

also demonstrated in a recent study by Pitel et al. (2006), who found that a participant with severe dysexecutive syndrome derived significantly less benefit from errorless learning than a participant with severe memory impairment but only mild executive deficits. This held true for the learning of both semantic and procedural knowledge.

9.4.3 Cognitive skills and the benefits of using cognitive mapping and landmark strategies

The fact that there was no correlation between scores on the neuropsychological tests and route-learning in the landmark and cognitive mapping conditions could be because the relatively small sample sizes available for these conditions (n=18) were not sufficient to detect significant relationships, as demonstrated by relatively low power for the analyses. However, it is also possible that the strategies provided in these conditions reduced the relationships between individuals' baseline cognitive ability and their route learning performance as it provided them with compensatory strategies. For example, people with poor verbal skills may not naturally have the ability to use a landmark strategy but when they are facilitated to use landmarks by the researcher, in essence, the cognitive impairment has less impact. Correlations showing that the worse a person's verbal skills the greater the benefit they derive from the landmark condition are consistent with this possibility. The fact that the correlations between verbal ability / memory, and route recall also disappeared in the map condition could suggest that providing a map may also compensate for deficits in these areas.

Concerning the discrepancy scores, the fact that measures of verbal ability and executive function are both inversely correlated with the amount of benefit derived from additional

strategies, that is, the fact that people with greater impairment in verbal skills and executive functioning benefit most from the addition of naturalistic techniques to errorless learning, has important theoretical and practical implications. It is consistent with the finding that people with severe memory impairment may have difficulty spontaneously using imagery mnemonics, but are able to utilise mnemonics when they are provided for them (Richardson, 1995). In this case, rather than imagery mnemonics, it appears that naturalistic route learning strategies may afford particular benefit to people with cognitive impairment (in verbal and executive function, and in some cases verbal memory), perhaps because they are similarly unable to spontaneously implement these strategies.

The fact that verbal memory impairment correlated with the advantage derived from the map condition is also an interesting finding, consistent with rehabilitation techniques favouring the provision of visual strategies for people with verbal memory impairment (Jones, 1974, cited in Kreutzer & Wehman, 1999, p155).

9.4.4 Implications

Although there are many possible reasons for the lack of correlations found between route learning performance and several of the neuropsychological tests, some tentative recommendations for rehabilitation can be made based on the correlations that did emerge. Given that the present tasks are an appropriate analogue for real life it would seem that verbal skills have a large role to play in route learning and this knowledge may help patients to understand the reason for any route learning difficulties they experience. However, even scores on these two tests combined only accounted for 18% of the variance in route-learning

performance, so the clinical utility of this finding may be relatively limited. There are large individual differences in route learning performance even in populations without ABI, as discussed at length in the Chapter 2. The fact that strategy use, amount of experience of wayfinding and self-confidence are all possible factors influencing route learning performance, along with the different patterns of performance that can be observed depending on the learning environment and outcome measures used in testing, it is not surprising that neuropsychological test scores account for a relatively small amount of the variance.

The correlations between benefits derived from particular learning conditions and neuropsychological test scores may be more useful, however. The finding that vocabulary scores correlated inversely with the benefit derived from both cognitive mapping and landmark use suggests that these strategies may be most appropriate to use in the rehabilitation of route learning with people with poor verbal skills. The exploratory ANOVA suggesting that strategies have little effect on the performance of people with spared verbal ability, but result in improved performance for people with impaired verbal ability supports this suggestion.

The correlation between verbal memory and relative benefit of cognitive mapping compared with simple errorless learning similarly suggests that people who display verbal memory impairment may benefit from being encouraged to create a cognitive map of the environment they need to travel through. Although the ANOVA exploring the relationship between verbal memory status (spared or impaired) and benefit derived from strategies did not quite result in

a significant interaction, the pattern of performance (depicted in figure 9) demonstrates a similar pattern to that observed with vocabulary scores.

Finally, the positive correlation between COWAT scores and the advantage for errorless over errorful learning suggests that people with poor executive function may be better suited to more active learning strategies than is found under simple errorless conditions. However, if it is possible to ensure that errors are minimised whilst maintaining an active role, such as in the errorless plus naturalistic strategy conditions, the benefits of errorless learning may be more evident for people with executive problems. This suggestion is also borne out by the exploratory ANOVA that shows that people with poor executive skills benefit from additional strategies but those with good executive skills change little or get slightly worse.

9.4.5 Limitations / Future Directions

The present study suffers from low power in the assessment of how neuropsychological test scores are related to performance under errorless learning combined with strategy conditions, and how they are related to the advantage of one condition over another. Therefore, it is not possible to conclusively rule out relationships existing that were not reported here. Future studies with larger sample sizes may reveal relationships between other cognitive abilities and the benefits of landmark or map strategies (or both) over simple errorless learning, or of errorless learning over errorful learning. They may also reveal straightforward correlations between cognitive abilities as assessed by neuropsychological tests and error scores for learning under the three conditions that had small sample sizes in the present study.

The fact that only 18% of the variance in route learning performance could be accounted for by verbal memory and verbal ability scores is consistent with Nadolne and Stringer's (2001) claim that neuropsychological tests are poor predictors of route learning ability. As route learning is a skill influenced by a great number of variables, future studies of route leaning in ABI and cognitive impairment may do well to consider other factors such as the learning technique (e.g. errorful learning, simple errorless learning, vanishing cues etc) and the type of compensatory strategy to be employed. The findings in the present study, while partly exploratory and based upon relatively small sample sizes, suggest that there are interesting and theoretically important relationships in this area that may have concrete applications in rehabilitation. Furthermore, whilst the present study only explores route learning, it is possible that cognitive deficits, learning conditions and task demands may interact in other important skill areas and we should begin to look beyond the simple errorless versus errorful learning paradigms.

CHAPTER TEN

GENERAL SUMMARY

The aim of the series of studies reported in this thesis was to investigate the effectiveness of a range of route learning strategies for people with acquired brain injuries, using both traditional errorless compensatory strategies that have been shown to benefit people with ABI (Baddeley & Wilson, 1994), and naturalistic route learning techniques that have been shown to be beneficial in studies of the general population (e.g. Cornell et al, 2003; Kato & Takeuchi, 2003).

In order to assess route learning techniques in an ecologically valid and controlled environment, a virtual reality setting was chosen and a pilot study (with participants without neurological impairment) reported in Chapter 5, was carried out that demonstrated the equivalence of route learning performance in the virtual town and real-world route learning performance. Having found a suitable environment in which to assess route learning, a second pilot study (Chapter 6) examined which naturalistic strategies were particularly effective for route-learning (again, in a sample of neurologically healthy participants). Combining findings from this study with those from the wayfinding literature (e.g. Cornell & al, 2003; Kato & Takeuchi, 2003), the strategies of landmark use and cognitive mapping were selected as potentially helpful techniques for use by people with acquired brain injury.

Before assessing whether these naturalistic strategies would be of benefit, however, a study was carried out (reported in Chapter 7) to confirm whether errorless learning, a technique used with considerable success to assist participants with memory impairment in the acquisition of (primarily verbal) material (e.g. Baddeley & Wilson, 1994), could be beneficial for route learning in ABI. Extending findings from several studies of verbal learning and learning of computer-based practical tasks (e.g. Glisky et al., 1992; Page et al., 2006; Wilson et al., 1994), it was found that errorless learning resulted in superior recall to errorful methods on a practical route-learning task. This demonstrates that a compensatory approach using memory techniques that do not necessarily rely upon external aids (which can be viewed in a negative light by people with ABI, see p.2), can significantly improve patients' route-learning performance.

Having confirmed the efficacy of errorless over errorful learning methods, the errorless technique was combined with the two naturalistic strategies identified as being particularly effective in the second pilot study; landmark use and cognitive mapping. Based on both empirical data (e.g. Evans et al., 2000; Kalla et al., 2001) and theoretical models (e.g. Craik & Lockheart, 1972) it was predicted that the additional naturalistic strategies would result in better route recall than simple errorless techniques. Furthermore, it was hoped that learning to employ naturalistic strategies in an errorless way would potentially give participants a method to apply to novel route learning scenarios, improving that the generalizability of the benefits errorless learning to a wider range of situations.

However, this prediction was not, on the whole, supported (although certain individuals may derive benefit from the naturalistic strategies, see below). There are several methodological reasons that could account for this, such as aspects of the way in which participants were induced to use the naturalistic strategies, and the relatively small sample size. However, it is also possible that it is genuinely not possible to significantly improve route learning via explicit strategies like landmark use, perhaps because errorless learning is primarily sub-served by implicit memory (Page et al., 2006). It is difficult to highlight any strong implications for rehabilitation from these findings as yet, therefore, and further work is needed to clarify whether naturalistic strategies are or are not useful additions to rehabilitation programmes using errorless learning.

Finally, Chapter 9 reported an investigation into relationships between cognitive profiles of participants with ABI, as assessed by a selected neuropsychological test battery, and performance on the route-learning task (under various conditions). Interestingly, verbal ability and verbal memory were the only skills that predicted performance on the main errorless route learning condition, demonstrating that verbal ability may be an important component of route learning proficiency. Of more practical relevance was the finding that the extent of the benefit derived from the composite "errorless learning + strategy" conditions was correlated with measures of executive function and verbal test scores. These findings provide preliminary evidence that people with particularly impaired verbal ability, verbal memory, or executive functioning, derive the greatest advantage from the addition of naturalistic strategies to errorless learning methods. Possible reasons for this have been discussed (Chapter 9). This finding suggests that although, as noted above, naturalistic strategies do not

improve on the advantages of errorless learning in a heterogeneous sample of people with ABI, they may actually be of use for people who are particularly impaired in terms of executive function and verbal ability. This emphasises the importance of considering cognitive profiles of patients when developing rehabilitation interventions (e.g. Chaytor & Schmitter-Edgcombe, 2003; Kreutzer & Wehman, 1999).

Whether the naturalistic strategies, which appear to be of some additional benefit to people with verbal or executive deficits, could be applied to route learning in novel scenarios and thereby promote wider improvement in performance, is an interesting question for further study. Other questions for future research, discussed in more detail in the preceding chapters, include: how effective the learning techniques reported here would be in a real-life setting; whether different naturalistic strategies (or the same strategies implemented in a different way) would result in greater improvement than seen in the present studies; and whether other tasks would benefit from a combination of errorless learning and naturalistic techniques.

In summary, the studies reported here highlight the need for more research into the benefits that might be derived from combining naturalistic strategies with errorless methods for route learning, and in particular demonstrate the importance of considering individuals' cognitive profiles in such studies. Preliminary evidence is presented for a relationship between verbal and executive impairment and benefit gained from the route learning techniques of landmark use and cognitive mapping. Most clearly, and with important practical implications, however, it is shown that errorless learning techniques can be applied to a highly ecologically valid practical route-learning task, resulting in greater retention than errorful methods.

Appendices

Way-finding questionnaire

	not at all	a little	A moderate amount	a lot	almost totally
1. I try to remember the sequence of lefts and rights I've taken on the way.					
2. I usually have no idea of the way so I guess.					
3. I find I have a 'birds-eye' map in my head that I can use.					
4. I think about whether I walked North, South, East, or West.					
5. As I go along, I am always aware of the general direction from which I came or in which I am going					
6. I use my memory of buildings and other landmarks seen on the way.					
7. I look for a tall building or landmark that is near my destination & walk towards it.					
8. I follow my instincts, without knowing how I do it.					
9. On the way there I occasionally look behind me to check where I've come from					
10. Please describe any other strategies you might use					

How confident do you feel in the following situations:

	No confidence	Little confidence	Moderately confident	Very confident	Totally confident
Finding your way to a certain place when you are in a car (as a driver or passenger)					
Finding your way back to your car (or the bus or train station) after shopping or sight seeing in a strange town.					
Finding your way back to a place you have only been to once.					
Returning to a certain room in a large building e.g. a large hospital or hotel.					
Following directions using a map a road map or A to Z					
Giving someone directions to somewhere in your home town					

Appendix C: Instructions given to participants under each learning condition:

Instructions for 5.2.3.1; Virtual reality route learning condition:

Participants were first given the following instructions:

"You are in a virtual city. I am going to drive along a route, and to help you learn the route I want you to try and imagine that you are actually travelling through the town, watching the route. I would like you to try and remember the route as accurately as possible. After I have driven through the whole route once, I'll reload the game to put you back at the start-point, and I will then start to go round the route again. To test your knowledge of the route, this time I want you to call out the direction in which I should go as soon as you know it. To get a correct answer, you need to call out the direction at least 5 seconds before I reach a junction. Even when the correct choice is to carry on straight past a turn-off, please make it clear that you know this by calling out 'straight on' or 'straight ahead' etc. I will carry on along the correct route whether or not you have called out the right direction, so you will not get lost - you will just not score a point when you give a wrong instruction. I want you to call out the directions for the exact route we followed originally, it's important not to try and take detours or shortcuts".

Because the instructions were fairly lengthy, they were then summarised as follows;

"To recap, I would like you to watch as I follow a route through the town, learning the route as well as you can so that you can call out the directions to me, when I return to the start of the route"

The participant was then driven around the virtual town. When the end of the route was reached, they were told;

> *"We are at the end of the route. Think about the route you have just seen while I drive back to the start (don't try and remember the route we are taking to get back to the start – there is no need for this)".*

The experimenter then drove back to the start-point of the route, and reminded participants;

> *"OK, now I am going to drive along the same route. I would like you to call out which direction you think it should be at each turn-off or junction. Remember to call out directions even when the right way is just to carry on straight ahead or straight past a turnoff. If you do not call out at least five seconds before the turn, you will be marked as wrong. Feel free to call out guesses if you like. If you call out a wrong turn, I simply will not take it, and will carry on along the correct route."*

Instructions for 5.2.3.2; Real world route-learning condition:

Participants in the real world route-learning scenario were told;

> *"We are at the start of a route. I am going to drive along the route, which will take about 5 minutes. I would like you to try and remember the route as accurately as possible. After I have driven through the whole route once, I'll return to the start and drive along it again, exactly as before. To test your knowledge of the route, the second time I want you to call out the direction that will be taken at a turn-off or junction, as soon as you know it. To get a correct answer, you need to call out the direction at least 5 seconds before the turn is made. Even when the correct choice is to carry on straight past a turn-off, though, please make it clear that you know this by calling out*

'straight on' or 'straight ahead' etc. The correct route will be followed whether or not you have called out the right direction, so you will not get lost - you will just not score a point when you give a wrong instruction or fail to call out an instruction in time. I want you to call out the directions for the exact route we followed originally, it's important not to try and take detours or shortcuts".

Just before the experimenter commenced demonstrating the route, she gave the reminder;

"To recap, I would like you to watch as I drive along the route, learning it as well as you can so that you can call out the directions as we go along it the next time".

Participants were then driven around the route. When the end of the route was reached, they were told;

"We are at the end of the route. Think about the route you have just seen while I drive back to the start (don't try and remember the route we are taking to get back to the start – there is no need for this)".

The experimenter then returned to the start-point of the route, and reminded participants;

"OK, now I am going to drive along the same route. I would like you to call out which direction you think it should be at each turn-off or junction. Remember to call out directions even when the right way is just to carry on straight ahead or straight past a turnoff. If you do not call out at least five seconds before the turn, you will be marked as wrong. Feel free to call out guesses if you like. If you call out a wrong turn, I simply will not take it, and will carry on along the correct route."

Instructions for 7.2.4.1; Errorless learning condition

The following instructions were given to participants in the errorless condition:

> "I'm going to walk around a route, calling out at each turn what way we need to go, and I want you to try and memorize the route as best you can. After I've been around the whole route, I'll go back to the start and, to help you learn the route, I'll go back around the route twice more. Then, the final time, after I've demonstrated the route three times, I'll ask you to direct me around it, and this time I'll be testing to see how well you've learned the route. If you direct me the wrong way, I'll go the way you tell me, to give you a chance to see that it's the wrong way and tell me to turn back. If you don't notice after 5 seconds, I'll tell you we've taken a wrong turn, and go back to the junction, so you'll never get lost. Again, I'd like you to try and really imagine that you are actually walking around the route yourself, not just watching as I go around it".

Instructions for 7.2.4.2; Errorful learning condition

Participants in the errorful learning conditions received the following instructions:

> "I'm going to walk around a route, calling out at each turn which way we need to go, and I want you to try and memorize the route as best you can. After I've been around the whole route, I'll go back to the start and ask you to direct me around it, to help you to learn the route. You will have two practice attempts to direct me around the route, and then, on the third attempt, I'll be testing to see how well you've learned the route. If you direct me the wrong way, I'll go the way you tell me, to give you a chance to see that it's the wrong way and tell me to turn back. If you don't notice after 5 seconds, I'll tell you we've taken a wrong turn, and go back to the junction, so you'll

never get lost. Again, I'd like you to try and really imagine that you are actually

walking around the route yourself, not just watching as I go around it".

Instructions for 8.2.4.2; 'errorless learning plus landmarks' condition:

Participants learning in this condition were given the following instructions:

"I'm going to walk around a route, calling out at each turn which way we need to go.

I want you to try and memorize the route as best you can. As I show you the route, I'm

going to stop at several turns to point out landmarks, to try and help you remember

which way to go. The landmarks will always be in or at the end of the road you need

to turn down. In other words, you will always need to walk towards or walk past the

landmark I point out. After I've been around the whole route, I'll go back to the start

and go round twice more. Then the final time, I'll ask you to direct me around it, and

this time I'll be testing to see how well you've learned the route. I will not point out

the landmarks this time, it will be up to you to try and remember where to turn. If you

direct me the wrong way, I'll go the way you tell me, just for about 5 seconds, to give

you a chance to see that it's the wrong way and tell me to turn back. If you don't

notice after 5 seconds, I'll tell you we've taken a wrong turn, and go back to the

junction, so you'll never get lost. Remember to try and really imagine that you are

actually walking (or driving) around the route yourself, to try and help you learn it".

### Instructions for 8.2.4.3; 'errorless learning plus cognitive mapping' condition:

Participants were given the following instructions

"I'm going to walk around a route, calling out at each turn which way we need to go.

I want you to try and memorize the route as best you can. As I show you the route, I'm

going to stop at several turns to show you a map of the route, to try and help you

remember which way to go. I will turn the map as we go around the route, so that the

direction we are going is always towards the top of the map. I will also draw an arrow

on the map each time I show it to you, so you can see where we are and what direction

we are going in. You will also notice that the whole route is marked on the map as a

filled in line, so you can see the layout of it. After I've been around the whole route,

I'll go back to the start and go round twice more. Then, the final time, I'll ask you to

direct me around it, and this time I'll be testing to see how well you've learned the

route. I will not show you the map this time, it will be up to you to try and remember

where to turn. If you direct me the wrong way, I'll go the way you tell me, just for

about 5 seconds, to give you a chance to see that it's the wrong way and tell me to

turn back. If you don't notice after 5 seconds, I'll tell you we've taken a wrong turn,

and go back to the junction, so you'll never get lost. Remember to try and really

imagine that you are actually walking (or driving) around the route yourself, to try

and help you learn it".
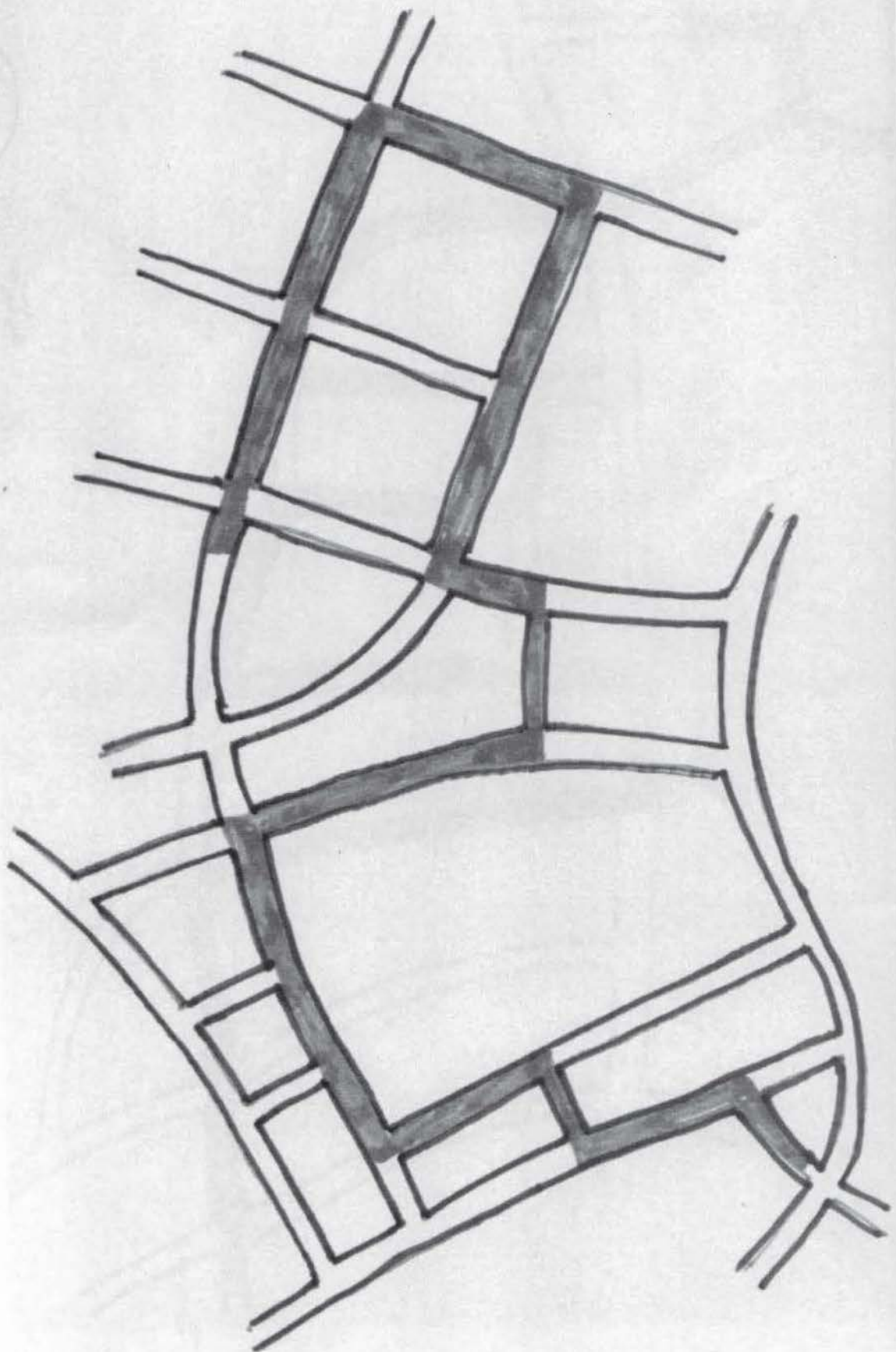
Route A
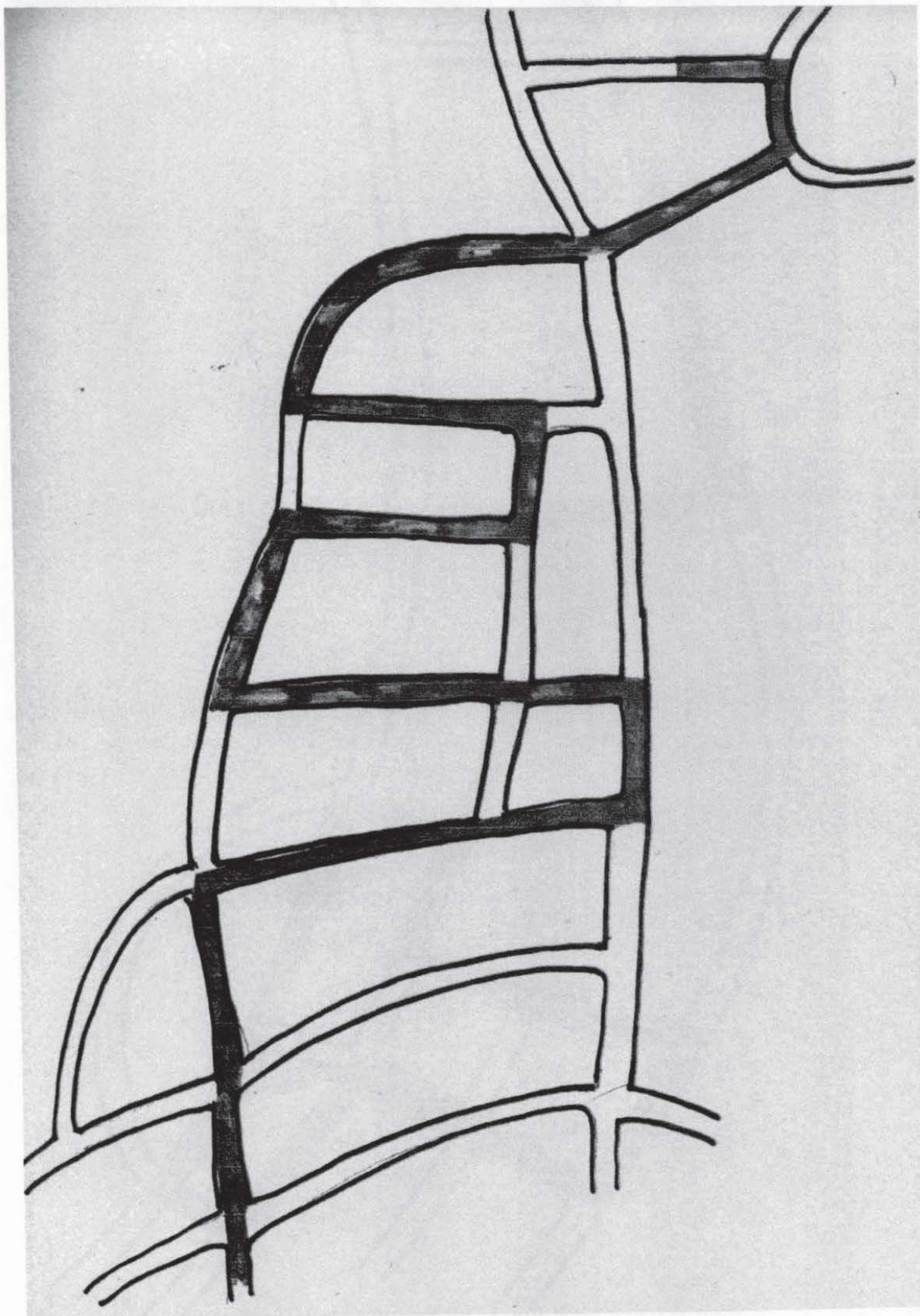
Route B
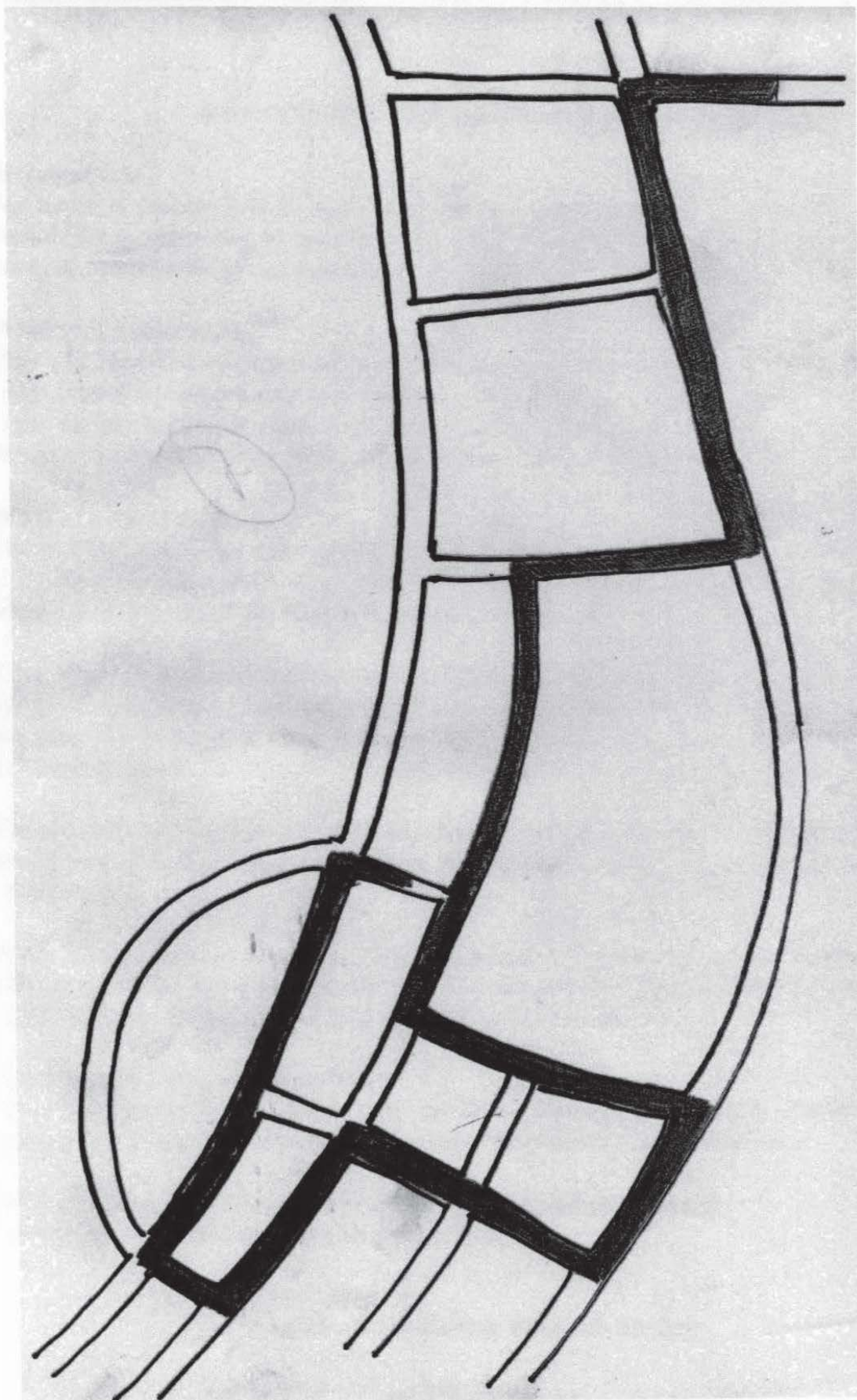
Route C

Participant information Leaflet

An investigation into route learning in virtual reality

Introduction
My name is Joanne Lloyd, and I am a PhD research student at Birmingham University. I would like to invite you to take part in a study of how people learn routes in a virtual reality, computer game setting, compared with how they learn routes in the real world.

What will I have to do?
You will be asked to carry out two route-learning tasks. One will involve watching a short route around a virtual town, displayed on a television screen, before being asked to direct the experimenter back along that route. The other will involve being driven along a short route through Bournville, before being asked to direct the experimenter back along that route.

What are the risks?
There are no bright or flashing lights involved in the virtual reality section of this experiment, it is like watching a television picture. However, if you have suffered any adverse effects when viewing a television screen in the past, you may not wish to volunteer.

Every care has been taken to minimize risks in the real world study – the route is located in a quiet, residential area, and you will be driven slowly and carefully. When driving conditions are poor, for example if there is ice or heavy rain, the real world section of the experiment will be postponed.

The structure of the experiment means that you will not be able to get lost; if you call out a wrong turn, it will be logged as an error but the experimenter will continue to drive along the correct route.

What if I do not want to take part or if I change my mind during the research study?
You are under no obligation to take part and are free to withdraw from the study at any time (up to the point of publication) and your data will be destroyed.

What happens to the information?
All information will be coded so that your name does not appear on it. There is a university requirement to keep the data for 5 years from the point of any publication.

What if I have more questions or do not understand something?
Please feel free to contact me with any questions.

Joanne Lloyd
Postgraduate Psychology Research Student
Tel 414 2942
Email

Thank you.

Participant information Leaflet

An investigation into route learning in virtual reality

Introduction

My name is Joanne Lloyd, and I am a PhD psychology research student at Birmingham University. I would like to invite you to take part in a study of how people learn routes in a virtual reality, computer game setting.

What will I have to do?

You will be asked to carry out a route-learning task. This will involve using a joystick to move through a town that you will see displayed on a TV screen.

What are the risks?

There are no bright or flashing lights involved in this experiment, it is like watching a television picture. However, if you have suffered any adverse effects when viewing a television screen in the past, you may not wish to volunteer.

What if I do not want to take part or if I change my mind during the research study?

You are under no obligation to take part and are free to withdraw from the study at any time (up to the point of publication) and your data will be destroyed.

What happens to the information?

All information will be coded so that your name does not appear on it. There is a university requirement to keep the data for 5 years from the point of any publication.

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

Please contact me via telephone or email:

Joanne Lloyd
Postgraduate Psychology Research Student
Tel 0121 414 2942
Email

Participant information Leaflet

An investigation into route learning in virtual reality

Introduction

My name is Joanne Lloyd, and I am a PhD psychology research student at Birmingham University. I would like to invite you to take part in a study of how people learn routes in a virtual reality, computer game setting.

What will I have to do?

You will be asked to carry out a route-learning task. This will involve using a joystick to move through a town that you will see displayed on a TV screen.

What are the risks?

There are no bright or flashing lights involved in this experiment, it is like watching a television picture. However, if you have suffered any adverse effects when viewing a television screen in the past, you may not wish to volunteer.

What if I do not want to take part or if I change my mind during the research study?

You are under no obligation to take part and are free to withdraw from the study at any time (up to the point of publication) and your data will be destroyed.

What happens to the information?

All information will be coded so that your name does not appear on it. There is a university requirement to keep the data for 5 years from the point of any publication.

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

Please contact me via telephone or email:

Joanne Lloyd
Postgraduate Psychology Research Student
Tel 0121 414 2942
Email

Patient information Leaflet

An investigation into route learning techniques for people with acquired brain injury

Introduction
My name is Joanne Lloyd, and I am a PhD research student at Birmingham University. Myself and my supervisor, Dr Theresa Powell, who is a clinical psychologist and lecturer in clinical psychology would like to invite you to take part in a study of how people can overcome difficulties learning routes to new places after they have suffered a brain injury (e.g. a head injury or a stroke).

What is the research study about?
When people have suffered a brain injury they often have physical and cognitive difficulties (e.g. memory and planning problems). There are a number of strategies that therapists use in rehabilitation to help people relearn. However, we feel that the strategies used at the moment don't take into account how people *naturally* learn these tasks and so we want to compare the two approaches.

What will I have to do?
We will first obtain the basic details of your injury from your medical notes.

We will then ask you some general questions (e.g about your education and employment) so we can get an idea of how you were before your injury.

We will carry out a range of tests on your memory, planning and speed of thinking. If you are happy for us to do so, we will give the results of these to your rehabilitation therapists as they would probably need to do them anyway.

You will then be asked to carry out a route-learning task. This will involve using a joy-stick to move through a town that you will see displayed on a TV screen. You will be asked to do this in two different ways so we can see which way helps you learn the route better. We will offer you the opportunity of doing the same thing with a real life task if you would like to stay in the study.

What are the benefits?
There may not be any benefits to you personally, although there is a possibility that it *may* help your current therapists decide the best way to help you learn routes and other tasks as part of your rehab programme. In the future it will help us to decide on the best way to help other patients learn and remember routes.

What are the risks?
We will ensure that you are supervised when carrying out the tasks and that your therapists are happy that the task is safe for you to perform.

What if I do not want to take part or if I change my mind during the research study?
You are under no obligation to take part and if you decide not to, this will not affect any aspect of your current treatment.

You are also entitled to withdraw from the study at any time (up to the point of publication) and your data will be destroyed.

What happens to the information?
All information will be coded so that your name does not appear on it. There is a university requirement to keep the data for 5 years from the point of any publication.

Who else is taking part?
100 other people who have suffered an acquired brain injury will be taking part over a period of four years.

What if something goes wrong?
It is very unlikely that something could go wrong as the study does not involve medication or physical interventions. However, the researchers are indemnified by the University of Birmingham.

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

What if I have more questions or do not understand something?
Please contact myself, or Dr Theresa Powell on the telephone numbers below or ask your key worker to contact us and we will get back to you.

What happens now if I decide to take part?
Either let your key worker know that you are willing or telephone us on the numbers below. We will then ask you to sign a consent form and we will answer any other questions you may have.

Contact names and numbers:

Dr Theresa Powell
Lecturer in Clinical Psychology
Tel 414 7207
Email t

Joanne Lloyd
Postgraduate Psychology Research Student
University of Birmingham
Tel 414 2942
Email

PARTICIPANT CONSENT FORM

An investigation into route learning in the real world and in virtual reality

I agree to take part in the above study. I understand that I am not obliged to do so and that I may withdraw from the study at any time and my results will be destroyed.

I confirm that the study has been explained to me and that I have understood this and had the opportunity to ask questions.

Participant's signature _____ Date _____

Name _____

Witness _____ Date _____

Name _____

PARTICIPANT CONSENT FORM

An investigation into route learning in virtual reality

I agree to take part in the above study. I understand that I am not obliged to do so and that I may withdraw from the study at any time and my results will be destroyed.

Participant's signature _____ Date _____

Name _____

Witness _____ Date _____

Name _____

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