ENHANCING SPATIAL COGNITION IN DISABLED CHILDREN USING VIRTUAL ENVIRONMENTS

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by

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Abstract

In nine experiments, computer generated three-dimensional environments were used to investigate the spatial learning processes of physically disabled children. Chapter 1 reviews the literature on spatial mapping. Chapter 2 introduces the background to virtual environments, and reviews the relevant experimental work in this field. Chapter 3 developed a novel paradigm for investigating configural learning in humans, based on a shortcut study previously used with hamsters. In experiments 1-3 optimal cue arrangement was investigated. Results indicated that four large cues, rather than small or continuous cues, were required in order to complete the shortcut task successfully. Experiment 4 demonstrated the paradigm to be a successful replication of the original task and a good measure of spatial ability. Experiment 5 compared the shortcut behaviour of physically disabled children with varying degrees of mobility. Children who had had limited mobility from birth were poorer at the task than those whose mobility had deteriorated with age, supporting the hypothesis that early independent exploration is important in the development of cognitive spatial mapping ability. In Chapter 4 (experiment 6) physically disabled children explored a simulation of a school and then completed tests of spatial ability within the equivalent real school. A successful transfer of spatial skills was demonstrated and thus the potential of this technology for training. In Chapter 5, experiments 7-9 examined the effect of repeated exposure to virtual environments. Experiment 7 confirmed that the skills disabled children acquired using virtual environments improved with exposure to successive environments. To eliminate the possibility that learning was influenced by non-specific factors, experiment 8 compared 3-D exploration and 2-D (control) exploration, finding spatial learning in the former to be superior. Experiment 9 confirmed the extent of improvement in spatial skills following intensive 3-D exploration. Chapter 6 draws conclusions from the experiments and suggests ideas for further research.
Publications

Experimental work reported in Chapter 5 (experiments 7 and 8) has been published in:

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1.1 Introduction

Humans and animals must adopt strategies to gauge their constantly altering position within the environment if they are to successfully negotiate "that great God-given maze which is our human world" (Tolman, 1948, p. 208). Glenberg (1997) points to the danger involved in living in a three dimensional world. Unsuccessful interaction with the environment can involve many hazards: such as falling, burning, drowning or starvation. Survival involves an ability to navigate this environment.

Neisser (1987) draws our attention to the stability of our environment. Although people and animals are constantly on the move, they normally have bases, homes, offices or places where they can be located. Each of us takes for granted an ability to return to places we have visited, often via the shortest most efficient route. McGee (1982) defined this spatial orientation as "the comprehension of the arrangement of elements within a visual stimulus pattern, the aptitude for remaining unconfused by the changing orientations in which a configuration may be presented and the ability to determine spatial relations in which the body orientation of the observer is an essential part of the problem" (p.4). The following work is primarily interested in the development of this spatial navigational skill. Spatial visualisation skills are briefly considered in chapter 5.
We see our world in three dimensions. Although the retina in the eye is a flat surface and therefore the images it receives are two dimensional, distance cues enable some two dimensional images to be perceived as distant in a three dimensional world. There are a number of distance cues (Cutting, 1997, describes nine major cues) that combine to determine perceived distance. These cues can be monocular (viewed through one eye) or binocular (viewed through two eyes). Monocular depth cues include relative size, superposition/occlusion and relative height. Relative size refers to smaller objects being interpreted as further away than larger objects. Occlusion is the effect when one object obstructs another, causing the overlapping object to be perceived as being nearer. The relative height of similar objects can enable distance perception, for example, objects that are seen as higher in the image are perceived as more distant.

The use of two eyes (binocular vision) has advantages for depth perception. Our two eyes enable us to see two slightly different images of an object and we use this disparity to calculate the object’s orientation in space. The term stereopsis is used to explain how the brain adds depth from this disparity between the different images from the two eyes. Binocular parallax (the angle between the two lines of sight) and binocular disparity (the difference between the retinal images on the two eyes when an object is viewed in depth) are both cues enabling the perception of depth (See Cutting, 1997, for a fuller review of depth cues).

Another type of depth cue arises from autonomous movement in space which appears to be crucial to the development of an effective internal spatial representation. Gibson (1966) stated that as the observer moves through space, there is a flow of stimulation
on the retinas, which leads to a better understanding of the three dimensionality of our world. "When the observer moves...the optic array becomes alive with motion" (Haber and Hershenson, 1973, p.332). As one walks through an area, new surfaces of objects come into view, textures change and details become sharper and fade as one moves towards and then away from objects. Gibson (1979) states that as we move through the environment we make choices and each choice of path opens up a new area and closes the one behind. After exploring we fit these areas together. The areas we can see and those we cannot, become one whole environment in our perception, so that from any place the location of another place is known, even though it is not in view. This internal representation of one’s environment is often referred to as a “cognitive map.”

Tolman (1948) describes a “map control room” in the brain which stimuli enter and are “worked over” and “elaborated” into “a tentative, cognitive-like map of the environment” (p.192). This “cognitive map” contains routes, paths and environmental relationships which are stored and can be used when responding to the environment. Thus accuracy of response to one’s environment is intricately linked to the quality of the cognitive map formed. This chapter will examine many aspects of spatial learning and the author’s understanding and use of the term “cognitive map.”
1.2 Theories of Space and the potential role of virtual environments in testing spatial skills

For many centuries the nature of space, and how humans perceive space, has been debated. Newton put forward the notion of absolute space as a framework that stands alone and independent of its contents, deeming the observer's position irrelevant. Thus if all objects were removed, 'space' would remain unchanged.

However, in contrast to Newton, Berkeley, argued that space was 'relative' not absolute. He saw space as a changing entity. Space changed with alterations in the position of objects and the viewpoint of the observer. In fact, Berkeley believed that space was psychological and doubted that physical space existed outside of the mind. There has been an historical move from absolute to relative notions of space (Liben, 1981). (For more detailed reviews see Jammer, 1969, O'Keefe and Nadel, 1978).

Ellis (1991) discusses a framework for understanding 'space' in terms of its content, geometry and dynamics. Content refers to the objects and actors contained within the environment. Geometry describes the properties of the environment, and dynamics illustrates the rules of interaction between actors and objects. Interesting issues are raised within this framework when it is applied to computer simulations. Simulations have been used by psychologists in order to investigate spatial learning. Simulations enable actions such as navigation and exploration. Regarding the content of the environment, the user can 'recognise' objects within the simulation and their own 'position' within this environment. However the nature of this environment is entirely
predetermined by the designer. This can be seen as a design problem or a flexible tool depending on the purpose of the test environment. When asking what should be included in a particular environment, a successful answer requires the selection of characteristics that enable one to tap into expectations developed from experience in familiar environments. Within a simulation, the illusion of 3D space is created by the use of depth cues some of which are described above. “These displays thus offer significant opportunities for geometric enhancement to emphasis important spatial information” (Ellis, 1991, p.9). The dynamic and interactive nature of simulations have advantages over static displays for spatial research as spatial learning is inherently dynamic. Additionally, when simulating an environment constraints and expectations can be incorporated (such as collision detection, preventing movement through objects and viewpoints positioned at eye level). Simulations can also be created relatively easily, and cost effectively, enabling research that may difficult or even impossible to perform in the real world.

Kant claims that “space and time are the very form of the human mind” (Ellis, 1991, p.xiii). Indeed everyday navigation and technological advances aiding exploration (flying, driving) involve complex spatial skill. The requirements of the human operator remain crucial, and machines must be tailored to suit the user. In order to gain optimal performance it is essential to gain knowledge of the user's abilities and limitations. This thesis focuses on the formation of the cognitive map (an internal representation of space). A distinction has been drawn between psychological space and physical space. Psychological space refers to the space of our perceptual experience, “any space which is attributed to the mind...and which would not exist if
minds did not exist” (O'Keefe and Nadel, 1978, p.6-7). Physical space refers to the three dimensional, euclidean world in which we live. These two types of space overlap and interact with one another. We can also distinguish between virtual space and physical space, as virtual environments do not exist in the physical world. The focus of this thesis is psychological space and investigates whether experience of virtual space, can be used to supplement physical space.

In the following sections cognitive mapping theories in animals, adults and children will be reviewed. As this chapter began with a quote from Tolman, who carried out many studies examining cognitive maps in the rat, the following section will briefly review the animal literature. However as eight of the nine studies carried out in this thesis only involve children, the development of cognitive maps in children will be the main focus of the chapter.

1.3 Cognitive mapping in animals

Animals need some form of effective navigation system in order to survive. O'Keefe and Nadel (1978) drew a distinction between the “Taxon” system (routes) and the “Locale” system (places) in the build up of spatial knowledge. Briefly, they put these two systems forward as alternative orientation methods (although not necessarily mutually exclusive systems, see Thinus-Blanc, 1996). The “Taxon” system involves using a series of S-R-S (stimulus-response-stimulus) instructions. Navigation involves moving from one landmark to the next by aligning oneself in relation to the
landmarks. This type of navigation involves a chain of directions. If one link in the chain is broken (a landmark is missing) then the subject is lost. Therefore this type of navigation is not flexible and only enables direct movement from one particular position to one particular goal. However the "Locale" system is a highly flexible system, based on the development and use of internal maps. The map represents a number of connected places. These places are independent of the subject's position and thus should allow the subject to navigate from any position within the environment and if a detour is required they should be able to adapt their route in order to reach the same goal. This distinction between routes and maps will be expanded on later in this chapter. O'Keefe and Nadel (1978) state that exploration is essential for the creation of internal spatial cognitive maps and in constantly up-dating them. An animal or human needs to constantly up-date internal maps of changing environments and also update one's own position in relation to the surroundings at any given moment in time.

When a rat is placed in a maze with food in one location, it explores until it finds the food. When replaced on a second occasion the rat makes fewer and fewer errors until it is running directly from the start to the goal. The school of animal behavioural psychologists believed this ability to be due to "simple stimulus-response connections." According to this view, the rat is responding to external stimuli such as sight, smell and sound and internal stimuli from viscera and skeletal muscles. However the field theorists, such as Tolman, believed that during the course of learning an internal representation of the test environment is created in the rat's brain. Tolman carried out various studies demonstrating the use of cognitive maps in
animals (see Tolman, 1948, for a review). He also distinguished between two different forms of map: a narrow, strip-like map and a second broader version. The narrow map purely links the position of the animal along a single path to the goal, whereas the broader map allows more flexibility. With the broader map, if the starting position is changed or the route is varied the animal will be able to use their representation to adjust their trajectories in order to continue to choose the correct route. Tolman suggested that narrow maps may occur for a variety of reasons, for example when an individual is deficient after brain damage, or where inadequate cues are available in the environment or following over repetition of a particular path (Tolman, 1948).

In various studies (Menzel and Menzel, 1979; Poucet, Chapuis, Durup and Thinus-Blanc, 1986; Poucet, 1989) animals explored spatial configurations and, following habituation (when the environment has been learned), a spatial element is altered. If the animal displays renewed exploration, it is suggestive that spatial novelty has been detected i.e. a comparison has been made between the present environment and the animal’s internal representation of the original environment. Thinus-Blanc (1996) states that the building of spatial representations may progress in stages depending on the time allowed for exploration of an environment, the cognitive abilities of the animal, and the demands of the task. The strategy employed will probably be dependent on the optimal ratio between cognitive load and efficiency.

Certain studies (Morris, 1981; Olton and Samuelson, 1976) which have claimed to examine the use of cognitive maps can in fact be explained by the use of other available strategies, such as a vector sum model (Thinus-Blanc, 1996). In this model,
landmarks are associated with goals, and an internal spatial map is not needed to solve the task. Different types of information are used by the animal to direct its trajectories.

This model cannot, however, explain spatial orientation in larger areas as spaces are visually "disconnected," and one cannot see the same landmarks from the start to the goal. Shortcut and detour studies provide evidence of the use of a cognitive map. In order to master these tasks, certain factors are unique to cognitive maps, such as the ability to recognise places within the environment from any location within it. Shortcuts and detours show oriented behaviour to be relatively independent of a given pathway. Information can be reorganised as it is not dependent on the order in which it was learned (Chapuis and Varlet, 1987; Poucet, 1985; Shepard, 1933).

Chapuis, Durup and Thinus-Blanc (1987) tested golden hamsters on a shortcut task after directed exploration. They concluded that after sufficient exploration, hamsters were using an internal representation in order to complete the task of finding food via a shortest most efficient route.

Of course, unlike humans, animals cannot be given direct instructions. The instructions are implied by or inherent in the task. If an animal fails on a spatial test, it does not necessarily mean that the animal had failed to use an internal map accurately, but perhaps attempted, unsuccessfully, to adopt another form of navigational system (Ellen, 1987). The animal's early experience, the amount of exploration and availability of cues, may explain the type of reference system used. Forgays and Forgays (1952) and Hymovitch (1952) found that rats raised in an enriched
environment quickly learned about their surroundings. However when this environment was rotated, rats raised in a bland environment relearned more quickly. Obviously depending on the available cues, the rats were using different types of representation. The rats in the bland environment were building an internal representation that was not dependent on cues.

This review does not comprehensively review the literature on animal studies of navigation, but introduces the paradigm used in the studies in chapter three. Broader reviews are available (for example, Thinus-Blanc, 1996).

1.4 Landmarks, routes and the cognitive map in adults

Most authors agree that humans carry spatial representations of their environment in their heads, yet there is constant debate concerning the type and content of these representations.

Siegel and White (1975) suggest a three tiered process in the development of spatial knowledge: the use of landmarks, then the adoption of route knowledge allowing fairly simple wayfinding, and finally internal representations of space, allowing more sophisticated methods of navigation. Sholl (1992) suggests a similar structure: landmark, place and environment.

Landmarks are used to identify particular geographical locations and are used to note particular locations in space as one travels around. For example, the clock tower in the
centre of the city of Leicester may be used as a central point around which to navigate when an individual is unfamiliar with the city. Landmarks may identify the start or end of a route, but more importantly they are used to keep track of a route and they are usually visual. Some environmental features are more effective than others as landmarks (Allen, Siegel and Rosinski, 1978). Livingston (1967a, 1967b) proposed the “Now Print!” mechanism where “at the time of a biologically meaningful event, the nervous system is stimulated to take a picture of itself” (Siegel and White, 1975). Siegel and White suggest that landmarks may constitute “meaningful events” and the nervous system may be continually “taking pictures” of them. If this is so, this theory could explain the importance of landmarks in cognitive map formation.

Routes are built up by connecting a series of landmarks. A route consists of a set of instructions such as “Carry straight on until you reach the traffic lights, turn right at the lights and then take the first turning on your left and the library is the third building along on the right.” This strategy is egocentric (dependent on the body’s location and direction of pointing in space) and is efficient as long as the links between successive turns are accurate.

“One can conceive, then, of the environment consisting of potential landmarks connected by potential routes. One can picture a spatial representation as landmarks (visual “pegs”) connected by routes (sensorimotor “lines”), to some extent guided by sequence learning.” (Siegel and White, 1975, p.24). Allen et al (1978) suggest the use of a route schema. They presented participants with either a logically sequenced or a randomised slide presentation of a walk. Route knowledge was learned when environmental features were not presented in their correct temporospatial order. They
concluded that a route schema was being used that had been acquired from previous experience of taking routes. Participants “were aided by a general knowledge of how to go about the task of cognitively representing large-scale environments” (p.628).

In order to successfully navigate around familiar environments, a more sophisticated method of navigation is adopted. When faced with a new environment, individuals may start to learn the environment by using landmarks and building routes to particular locations, but as they become more familiar with the environment they begin to use more flexible strategies based on their cognitive map.

“The primary function of the spatial representation is to facilitate location and movement within the larger physical environment and to prevent getting lost” (Siegel and White, 1975).

A cognitive map applies to the mental images that individuals build up as they become more familiar with their surroundings. This type of representation is allocentric (not dependent on the body’s position in space or direction of regard) and thus is extremely flexible. These representations consist of a network of routes that allow more effective navigation of one’s environment. Cognitive maps, because they incorporate places that are identifiable independently of approach direction, possess the unique advantage that they can be used to navigate to, or indicate the direction of, any given target location (not just a prominent landmark) from any starting position within that environment. For this reason they enable the adoption of short cuts and detours. Thus pointing, taking detours and taking short cuts are particularly sensitive
and unambiguous indicators of whether a subject has indeed acquired a good quality "map" of an environment.

Pick and Lockman (1981) describe three properties of spatial maps: reversibility, transitivity and enabling detours. If a person travels from A to B they should be able to travel from B back to A. Travelling between A and B and then B and C, suggests knowledge of the route from A to C. Finally, if A to B is travelled by one particular route there should also be sufficient knowledge to travel between these two places via other routes.

However the distinction between routes and cognitive maps is not as clear cut as it may first seem. Appleyard (1976) demonstrated that people who had lived in a city for under a year drew maps which illustrated routes. However people who had lived there longer emphasised boundaries and landmarks. Devlin (1976) and Evans, Marrero and Butler (1981) both found landmarks featuring strongly after route knowledge.

Siegel (1981) claimed that the structure of the map is dependent on the needs of the individual. Lynch (1960) suggests that the cognitive map is a product of the number and type of landmarks and the number and type of past experiences one has had in a particular location. The kind of navigational strategy used is dependent on factors such as the availability of landmarks, the demands of the task and the experience the individual has of this (Wohlwill, 1981) or similar environments (Pick and Lockman, 1981). Humans and animals, as Toates (1994) suggests, may use different forms of orientation depending on the cognitive abilities of the individual and also the
complexity of the task. The same individual may use guidance strategies for some
tasks and a cognitive map for others (Pailhous, Lepecq and Peruch, 1987). The size of
the environment may affect the way individuals store or use spatial information since,
"the reference system chosen by an individual is closely tied to the specific space in
which she is located" (Acredolo, 1976, p.171). In some cases it could be advantageous
to use route knowledge as it is generally quick and easy to follow, with a small
information load and no necessity for decoding. It is probably the most efficient
method of navigation if one is only interested in reaching one particular goal (O’Keefe
and Nadel, 1978).

Even though humans have the ability to form and use cognitive maps it does not
follow that they are normally used. However if places are going to be revisited, and a
flexible navigational system is required, a cognitive map is invariably preferable. This
allows navigation from any point within the environment to a variety of goals. Routes
allow one to reach a specific goal but they are inflexible and must be used in the
correct sequence if they are to be a successful means of navigation. If a wrong turn is
taken when following a route or if a path is blocked, the individual will become
irredeemably lost, unless they can relocate via landmarks. The use of landmark
strategies, particularly local landmarks, involves some interpretative difficulties, since
landmarks that are obvious environmental features to one individual may not be
prominent to another and they may be overlooked.

McDonald and Pellegrino (1993) comment that it is not surprising that varied
navigational systems are used considering the number of environments people explore
and the different ways that they interact with these environments for different purposes.

The majority of research in this field has concentrated on children’s navigational ability. The general landmark, route, configuration progression appears to develop with age. However when an adult encounters new environments it is likely that the same progression takes place, but it is completed in a much shorter time span due to repeated exploration and knowledge about other similar environments that have been encountered (Siegel and White, 1975).

Thorndyke and Hayes-Roth (1982) state three important points about spatial cognition. Firstly, people build up their spatial knowledge from a variety of different sources: navigation through the environment, a wide variety of different forms of maps, verbal descriptions and photographs. The knowledge gained from each of these sources is integrated to form spatial knowledge. Secondly, dependent on the knowledge they have, people use different methods when making spatial judgements. Thirdly, the accuracy of any spatial judgement is dependent not only on the accuracy of spatial knowledge but also on the computations performed on this knowledge.

Presson and Somerville (1985) argue that there are two methods by which people gain spatial information. Primary spatial activity, being visual and/or kinesthetic direct interaction with one’s environment, is contrasted with secondary spatial activity, such as maps. In the latter case, although spatial information is acquired, it must be translated before it can be used. Important differences lie in the way in which spatial
knowledge can be used dependent on the way it was originally obtained. Learning from a map (secondary spatial activity) provides a figural representation that is precise but is orientation-specific, whereas learning a route through direct experience, actually travelling along it (primary spatial activity) produces a less precise representation but one that can be used in more flexible ways as it is not tied to one orientation (MacEachren, 1992; Presson and Hazelrigg, 1984). One of the main features of an effective cognitive map is that it is orientation free, normally due to having been built up from navigation and successive encounters with environments, in which the place has been viewed from many different vantage points.

In studies which controlled the amount of exposure to the environment, participants who had limited navigational exposure gained route knowledge but not an accurate cognitive map. However with repeated exposure to the environment their orientation ability improved implying a more accurate cognitive map (Allen et al., 1978; Herman and Siegel, 1978; Kozlowski and Bryant, 1977). Environmental complexity did not affect wayfinding ability when participants were familiar with the environment (O’Neill, 1992).

In a study by Thorndyke and Hayes-Roth (1982) adult participants learned places within an environment and routes connecting them either by memorising a map or by navigating through the real environment. All participants then performed spatial knowledge tasks. They found that with moderate exposure, map learning was superior for judgements of relative location and straight line distances among objects. However navigation was superior for orientating oneself with respect to unseen objects and for
estimating distances. With prolonged exposure the superior spatial knowledge acquired from maps fades. The authors state that navigation through an environment produces a superior, flexible cognitive map. However acquiring knowledge from a map only required a short time, whereas the repeated exploration of an environment takes much longer. Although navigation may impart more accurate spatial knowledge it is not always possible to repeatedly explore a particular place.

In the studies outlined in this thesis repeated exploration is possible and is emphasised as one of the important features of using simulations, allowing children to develop cognitive maps. They explore until they feel that they “know” the environment.

1.5 Terminology

Tolman (1948) claimed that, “in the course of learning something like a field map of the environment gets established in the rat’s brain” (p.192).

The term cognitive map, which is widely used in the literature on spatial knowledge, might imply a static picture, though many authors have deemed this unrealistic. As cognitive maps appear to integrate information that is learned from many encounters with an environment, it is unlikely that the cognitive map consists of a static picture. Kuipers (1978) suggested that instead of one map, we may use many maps that are loosely linked together. Appleyard (1970) found that representations were fragmented with some detailed areas next to seemingly barren areas. Thinus-Blanc (1996) coined the phrase “spatial integrating system” to emphasise the dynamic properties of the
cognitive map. Cognitive maps possess many distortions (Siegel and White, 1975) and are therefore not like metric survey maps. Blaut, McCleary and Blaut (1970) claim that the cognitive structure “has the functions of a map but not necessarily the properties of a pictorial mental image” (p. 337). Byrne (1979) argues that cognitive maps are likely to be more representative of a network map than a survey type map. Various studies have shown that within internal maps features are normalised, for example roads are assumed to be parallel with junctions at 90 degree angles (Byrne, 1979). Chase and Chi (1981) state that the normalising errors are the result of the hierarchical structure of spatial knowledge. Errors are due to grid structures that people use to organise their internal maps. However these problems may be derived from paper and pencil testing, and they may not be significant when actually navigating one’s environment (Levine, Jankovic and Palij, 1982).

Another reason for disputing the map-like image is that what is experienced when wandering through environments is a number of local views from within the environment and not a bird’s eye view (McDonald and Pellegrino, 1993; Neisser, 1987; Strelow, 1985). “One basic problem with cognitive-map concepts is that the survey-map characteristics they posit in memory have no obvious connection to the traveller’s actual perceptual experience of the environment... That is, the survey-map is a bird’s eye view of the environment, whereas what we experience is a frontal view” (Strelow, 1985, p.241).

Neisser (1976) stated that spatial information was acquired as part of a perceptual cycle. This perceptual system consists of schema that organise the information
acquired. "A schema is that portion of the entire perceptual cycle which is internal to the perceiver, modifiable by experience, and somehow specific to what is being perceived. The schema accepts information as it becomes available at sensory surfaces and is changed by that information; it directs movements and exploratory activities that make more information available, by which it is further modified” (p.54).

Rather than maps, Neisser proposes that there are internal plans for obtaining information from the environment that predict what we are about to see, and update any changes from the expected image. Neisser (1987) stresses that the cognitive map is not a picture and is not part of the visual system but is a sense of “spatial knowing.”

It seems unlikely that we view the world in three dimensions, convert it internally into a map-like two dimensional image, and then transform this internal image back into three dimensions when we need to navigate through a particular area again.

It is also important to remember that although vision is usually the dominant sense, all the other senses can be used in the creation of an internal map of one’s surroundings (Siegel and White, 1975).

However cognitive maps created from studying a map rather than through exploration maybe picture-like, in that they can be scanned. Kosslyn (1980) asked people to draw a map of an imaginary island and to place various landmarks on it. When they had memorized the map, it was removed and they had to imagine it and focus on a particular location. The experimenters gave them the names of various landmarks and
for each landmark they scanned their image until they reached it and then pressed a button. The time taken to respond depended on the distance of the landmark from the starting position. This suggests that people can scan certain internal images.

Yet again the method of gaining the information, along with how it is to be used in a particular situation, determines the type and form of representation. The form of representation also most probably differs from person to person.

Due to the unresolved question of the most appropriate term to use for the image of the environment that is formed in an individual’s head, in the following studies the traditional term ‘cognitive map’ will be used interchangeably with the term ‘internal representation of space.’

1.6 Cognitive maps in childhood

The quality of childrens’ cognitive maps is dependent on a variety of factors such as familiarity with the environment, normally due to repeated exposure, the provision of landmarks, and locomotion allowing self initiated exploration.

Piaget states that cognitive development is not biologically programmed but is constructed by children as they actively explore their world. He claims that children construct models of their world and test these models against their experience and ‘accommodate’ and ‘assimilate’ (alter and update) the model accordingly (see Feldman, 1980, for an overview of Piaget’s theory). Piaget and Inhelder (1956), in
probably their most famous study, showed children a model of a range of three mountains, each mountain coloured differently. Using cardboard shapes, the children had to recreate the model as it looked to them. Then they were asked to depict the range as it would look if they imagined it from a different viewpoint. Children younger than seven or eight were unable to do this. They simply created pictures from their own viewpoint. Only the older participants could give a response independent of their own physical viewpoint. Piaget and Inhelder put children's failure on this task down to egocentricity. They stated that only as children developed and explored did they begin to see the world from different perspectives unrelated to their particular viewpoint. Shemyakin (1962) found a similar progression of topographical representations. Shemyakin asked children and adults to draw maps of their neighbourhoods. Six to seven year olds merely drew the routes they usually travel. They illustrated the route of their journey home from school reasonably accurately but only drew those parts over which they travelled and not the remainder of the street or roads leading off this route. Nine to ten year olds created more complex drawings with routes leading off the main route but these were still unconnected. However by twelve years children were drawing accurate connected maps (see also Catling, 1979).

However more recent studies have shown that children as young as two can behave nonegocentrically, adopting an allocentric viewpoint. The ability to detour around barriers was achieved by infants at the end of their first year (Lockman, 1987). Lockman concludes that "by the second year, we can already see that the child is on his or her way toward becoming a skillful navigator through the environment" (p.255). It has been suggested that the nature of the three mountain study was
problematic; it may not have been sufficiently engaging or not relevant to the type of task that a young child is used to undertaking (Young, 1989, p.39). Piaget’s experiments concentrated purely on small scale space so it is questionable whether his conclusions can generalise to large scale environments which are more representative of real world experiences (Herman and Siegel, 1978). Small scale space is an area which can be viewed simultaneously from one vantage point, whereas large scale space requires movement in order for an individual to view the entire environment. Shemyakin’s study was dependent on map drawing, which may also have been misleading. The problems of map-drawing are referred to later in this chapter.

Acredolo (1978) sat an infant in the middle of a room with a window on either side. Children learned to expect an event that took place at a particular window when a buzzer sounded. Each infant was then rotated 180 degrees. When the buzzer sounded, the direction in which the child looked was recorded. If the child turned their head in the same direction in relation to the body midline as previously (thus looking towards the wrong window) this was recorded as an egocentric response. However if the child turned their head the other way, towards the target window, this indicated an allocentric outlook. They found that six to eleven month olds illustrated egocentric responding, however at sixteen months allocentric responses were observed. When the experimenters added a landmark (a yellow star around the target window) six month olds still demonstrated egocentric responding, but fifty percent of the eleven month olds looked at the target window, suggesting that at this age children were beginning to understand and use landmarks.
Acredolo and Evans (1980) used four different landmark conditions: no landmark, the star, lights surrounding the non target window and yellow stripes on the non target wall. The data from the no landmark and star conditions corresponded to that of the last experiment. The lights and stripes caused mixed responses even in six month old children. The authors concluded that objective responding takes place at sixteen months in the absence of any landmarks. They suggest that sensitivity to landmark information increased with age. At first landmarks need to be very salient to compete with egocentric responding, but as children get older they respond to less salient landmarks. Cornell and Heth (1979) and Rieser (1979) found that infants between six and nine months were not sensitive to objective spatial information. However McKenzie, Day and Ihsen (1984) taught infants to anticipate an event from a particular location that remained constant from two different directions and then tested the children from a third novel position. They found that infants as young as six months visually anticipated the position of the event from the new direction, indicating that they are far less egocentric than previously thought. This suggests that the design of previous studies may have encouraged infants to make egocentric responses.

Acredolo, Pick and Olsen (1975) tested childrens’ ability to recall the spatial location at which an event took place. Eight year olds were more accurate than four year olds when there were few landmarks. This study supported Piaget’s theory in that spatial knowledge firstly depends on landmarks and becomes less landmark dependent with age.
Piaget (1954) stressed the importance of walking in the development of children's understanding of space. Bertenthal, Campos and Caplovitz Barrett (1984) suggest that a shift from an egocentric to an allocentric point of view may be related to locomotion. Emergence of self-produced locomotion leads to the use of a landmark code. As a child progresses to walking they become aware of the relationship between themselves and the surrounding environment, and their spatial awareness increases the more they explore.

Pick (1976) states that "as the child becomes older, the ability to construct, integrate or infer spatial relations is applied increasingly to larger and more complex spaces that are more and more remote from the body" (Lockman, 1987, p.253). Thus locomotion fundamentally changes the way in which the child interacts with the environment (Gustafson, 1984).

Siegel and White (1975) state that locomotion in space appears to be an almost essential condition for the construction of a cognitive map. Mahler, Pine and Bergman (1975) suggested that walking allows children novel experiences such as advanced visual awareness, exploration of their surroundings and a sense of autonomy. Bremner and Bryant (1985) present spatial awareness as developing on a continuum from 'no activity, little spatial appreciation' to 'extensive activity, a good sense of space.' In the first few months of life babies receive only a few rather static views of their surroundings and they probably do not integrate these views into a whole unitary representation. It is possible that integration could occur as children are carried around
by their parents but it is unlikely that passive information is sufficient to create an accurate representation. Sitting provides new views and a sense of space so that “some of the properties of spatial relations may be systematically disentangled once infants can sit up and explore the environment by controlled movements of head and body” (Bremner and Bryant, 1985, p.69). Crawling allows the infant to become aware of the dynamic relationship between self and the stable environment and walking allows full spatial awareness. Independent movement assists the change from an egocentric to an allocentric outlook.

Numerous studies have stressed the importance of self produced locomotion in this respect (Billinghurst and Weghorst, 1995; Fraiberg, 1959; Gibson, 1979; Held and Hein, 1963; Mahler et al., 1975). Acredolo, Adams and Goodwyn (1984) looked at active versus passive movement at twelve and eighteen months, in order to assess whether the onset of movement was important in spatial orientation. They conclude that active, self-produced movement experienced at an early age is associated with a better grasp of spatial relations. They argue that active movement increases the likelihood that close attention will be paid to important spatial features.

Bertenthal et al. (1984) tested three groups of eight month old infants: a) crawling, b) not crawling but used a walker, c) immobile. They found that the two mobile groups (a and b) showed less egocentric responding. Greater mobility has also been associated with better visual tracking (Horobin and Acredolo, 1986). Glicksman (1987) failed to show that children with more locomotor experience performed better on spatial tasks. They tested infants’ ability to keep track of object locations as they
were moved through the environment. However in this study children were only rotated; no translation of position was used and there were no landmarks, suggesting that translation and landmarks may be the important differences between those children who had experience of locomotion and those who had not. However, Rieser (1979) found that six month olds demonstrated allocentric orientation when their change of position was merely via passive rotation around the line of sight rather than movement across the room and then a rotation. A small experimental space and just one target window may have enabled this response (Pick and Lockman, 1981).

Hazen, Lockman and Pick (1978) found that, after being walked between 4 or 6 rooms, three olds were able to reverse a route but could not make inferences about sections of the environment through which they had not directly travelled. This suggests that they were able to update egocentric responses but did not possess an overall representation that could be updated after a change in position. Herman and Siegel (1978) found that when children walked through a large model town and then constructed the layout of the buildings, accuracy of construction increased with age and also with repeated exposure to the environment. They also found that walking through the environment was no more effective than viewing it repeatedly. This could imply that the motor component of movement is not as important as visual familiarity. However there may be a flaw in the nature of the task, in that the child could always see the experimenter walking, at any point in the environment, and thus it was not truly a large scale space, according to the definition given above, i.e. that a large scale space is one that cannot be viewed in its entirety from one position. Ladd (1970) asked adolescents who lived in the country to draw maps of their neighbourhood and
found that the detail and quality of the resulting maps were positively related to the 
adolescents’ normal activity range.

Locomotion is deemed important but many authors have suggested that autonomous 
choice of direction and self-directed activity are equally important (Foreman, 
Foreman, Cummings and Owens 1989a; Hart and Berzok, 1982; Herman and Siegel, 
1978). After four years of age children can remember spatial locations but they seem 
to need independent locomotor experience within space to use their ability 
strategically. In a radial search task, active choice was the most important factor for 
successful performance, but locomotion without free choice was nearly as effective 
(Foreman et al. 1989a). Passive exploration alone may not be sufficient to build up 
spatial knowledge. Campos, Svejda, Campos and Bertenthal (1982) suggest that 
children “switch off” spatially when they are picked up and carried, perhaps because 
someone else has taken control and they no longer feel the need to attend to their 
surroundings. Feldman and Acredolo (1979) found that self-directed exploration by 
three to five year olds improves their attention to relevant cues, whereas nine to eleven 
year olds, having a better spatial sense, demonstrate superior spatial knowledge 
regardless of whether they are tested actively or passively (see also Poag and Cohen, 
1983). Passive versus active exploration is discussed further in chapter 2.

Children need to be taught which are the most effective landmarks to use for 
orientation purposes. Siegel and Schadler (1977) asked six year old children to build, 
from memory, a 3-D model of the layout of the furniture in their classrooms. Clusters 
of furniture were reproduced, but the relationship between clusters was inaccurate.
Children's representations consisted of several “mini-spatial-representations,” not representations of the whole environment. They found that increased familiarity, and the provision of significant landmarks, enhanced young children's' cognitive maps of their classrooms.

With repeated exposure the adult and, with development, the child, is able to take a number of different perspectives and choose which one to use to solve a particular problem. Siegel and White (1975) stated that the development of a cognitive map is only possible after route knowledge has been acquired and an objective frame of reference has been adopted.

Rider and Rieser (1988) found that when asked to point to a target location, young children tend to point to the path they travelled along, rather than pointing directly to the correct location, as older children do. This is taken as showing an egocentric viewpoint rather than an allocentric one. Competence at pointing emerges between two and four years of age. They suggest that although visual cues are important they may be distracting if a child does not know how to use them. They say that children need to overcome "what seems like a slavish devotion to the visually specified path to the hidden target" (p.493).

The age when a child's frame of reference changes from egocentric to allocentric depends on the task, cues and the complexity of the required response. Acredolo (1976) found that in a task involving locomotion this change took place between four
and seven years of age, whereas when the response consisted only of looking, the change took place between six and sixteen months.

Hart (1981) sums this up by saying that “children’s ability to represent the geographic environment must be related not only to intellectual ability, but also to such factors as their degree of access to the landscape and their freedom to manipulate it” (p. 195).

The landmark, route, configuration sequence seems to be loosely followed by both children and adults. However, the progression is slower in children, due to the time taken to develop a flexible frame of reference, the ability to understand what constitutes a landmark, and finally, the development of mobility and thus exploration of the surrounding environment.

1.7 Problems assessing the cognitive map

“Since we are limited by the range of ways in which we can make knowledge explicit, we always know more than we can tell” (Downs, 1981, p. 148).

Authors have used words, images, maps and models to attempt to extract the form of the cognitive map. However, one can never be sure that the task used is providing the ‘full picture’, as what is being externalised is a rererepresentation of our cognitive map, which in turn is a representation of the world! Tobler (1976) sums this up nicely: “We assume that the subjects being studied have a representation of their environment and that this is somehow maplike and can be observed by some kind of measurement
procedure. I am not convinced that the basic assumption is meaningful, but I have been unable to devise an experiment that would force me to give it up. Clearly, some representation of the environment is required, but whether this is hierarchical or maplike is not known.” (p.70).

In order to examine the form of cognitive map that individuals possess, various means of externalising this representation have been used. Sketch maps are often used. However many authors argue that they do not present a true picture of the real structure involved (Evans and Pezdec, 1980) due to data analysis problems and bias due to drawing ability (Evans, Fellows, Zorn and Doty, 1980).

McDonald and Pellegrino (1993) argue that children may have good configurational knowledge but may not be able to externalise it. Glicksman (1987) suggests that the nature of the tasks set for infants may imply the spatial strategy to be used. If children use an egocentric strategy during training then they will probably use the same system when being tested. For instance, as stated earlier, McKenzie et al (1984) taught infants, viewing from two different locations, to expect an event in a particular place. Children were then tested from a new third direction and children at six months proved to be far less egocentric that has been claimed in previous studies. The nature of Acredolo’s studies, in which the child had only to look in one direction, may have encouraged egocentric responding.

Due to the problems children have in externalising their knowledge in experimental spaces, authors have in some cases tested children in real environments. Childrens’
performance on these tasks is far superior to that on traditional map, paper and pencil tasks, so that many conclude that childrens' internal representations of space are probably much more sophisticated than previously shown (Liben, 1981). But testing in real world situations is not always practical and can often be very time consuming.

Piaget and Inhelder (1956) define “practical” space, the ability to make inferences in space, and “conceptual” space, our means of representing space, as two very different abilities and it does not necessarily follow that behaviour in “practical” space illustrates the content of our “conceptual” space.

Herman and Siegel (1978) point out four problems in previous studies assessing childrens’ cognitive maps. Firstly, verbal recall and drawing may confound spatial knowledge with verbal and artistic skills. Secondly, many studies assess spatial knowledge in small scale space rather than in large scale space. Small scale space is not representative of real world situations, as rarely can we see all points of the environment from one position. Thirdly, children view the world in one scale and are then tested in a smaller or larger scale space which may confound their spatial knowledge with the ability to scale up or scale down. Fourthly, children may not be given adequate experience of the environment to have the chance to form an effective map (see Acredolo et al, 1975).

This is not to say that map drawing is not valid; the development of drawing of maps has been used extensively to demonstrate how children progress spatially with age (see Feldman, 1980, for a description of spatial development as revealed by drawn
maps rated under six levels of spatial reasoning development). Many map tasks, despite their limitations, are good predictors of spatial knowledge if they are used in an appropriate design. A combination of tasks may be essential to gain a more rounded view of the type of information that children and adults are handling and using when navigating environments.

1.8 Spatial problems encountered by disabled people

Most able bodied children and adults have no difficulty finding their way around and take their navigational skills for granted. However for children or adults with physical disabilities that limit their mobility, wayfinding can be a very difficult task. The causes of such deficits are probably varied, including damage to spatial brain structures, or experiential factors related to mobility status and limitations. Physically disabled children, whose disability limits their autonomous movement, are often neither able to explore an environment fully nor routinely encode routes and places as able bodied children would.

Even children who have some form of assistance (via the use of a wheelchair, or being transported by an able-bodied assistant) may be limited by physical access, or by relying on their assistant to make route choices. Generally they will be prevented from taking incorrect routes, and will thus be denied the opportunity for error correction. Assistants will normally take the shortest routes to places in order to prevent unnecessary effort in taking long, inefficient routes. As a result, they limit the child’s opportunities to experience spatial choice, error correction, shortest route deduction,
path integration and the other learning experiences that are probably crucial for the elaboration of spatial cognition in able bodied individuals. Over a period of time, and especially in early stages of development, the cumulative effect of passivity and limited autonomous exploration may deprive the child or adult of the motivation and/or ability to learn about new environments and form effective internal maps with which to navigate (Foreman, Orencas, Nicholas, Morton and Gell, 1989b). The overprotection of parents can further limit autonomy (Middleton, 1991).

When tested, children with mobility limitations have difficulty forming internal spatial representations of their environments, which is perhaps not surprising in view of the importance of self-directed exploration in the establishment of both specific and general aspects of cognitive mapping skills. Although it is often difficult to establish a causal link between poor exploratory experience and poor spatial mapping, there is strong suggestive evidence available. Foreman et al (1989b) tested ten physically disabled children, educated in mainstream schools, on measures of spatial awareness and cognitive mapping skills, using a variety of pointing and map-drawing tasks. Compared with closely matched, able-bodied class mates, the physically disabled children were worse at drawing plan maps of their classroom, placing missing objects on an outline map of the classroom, and pointing in the direction of distant landmarks on the school campus.

Simms (1987) in her work with children with Spina Bifida states that the childrens' physical disabilities only allow restricted environmental experiences: “certainly for the very young child and in a more social/environmental sense for the adolescent, who
is unable to travel about in his immediate or distant environment freely and independently. His experiences in, and interactions with, the environment are therefore fewer and his cognitive mapping ability might be more limited as a result” (Simms, 1987, p.53). Inefficient locomotion in the disabled child may inhibit the development of a cognitive map due to drained energy and the extra attention needed for successful movement through the environment. The child may direct all their energy and attention to reaching the goal rather than attending to their surroundings (Campos et al. 1982). Bertenthal et al (1984) discuss a case study of a child who showed late development of spatial skills due to the use of an orthopedic device that caused delayed locomotion.

Billinghurst and Weghorst (1995) state that human spatial behavior relies on the quality of cognitive map formed. They suggest that an inaccurate or distorted map leads to disorientation. Thus, if a child is not able to build an integrated representation of their environment, due to limited exploration, they will obviously experience problems when trying to use this representation to navigate. Disabled individuals comment upon the insecurity that can arise from their poor understanding of spatial aspects of environments (Foreman, Wilson and Stanton, 1995). If a means can be found to improve spatial knowledge in disabled children, by providing independent exploratory experience from an early age, this could have a substantial impact on their overall quality of life.

Computer-simulated environments appear to provide an ideal solution to this problem. Children can explore computer simulated environments independently using
appropriate interface devices that are tailored to their particular skills and disability. They can explore freely and safely. Such exploration should increase their confidence in subsequent real life exploration, particularly if they can visit an environment in simulated form before encountering the real one. Moreover, spatial disorientation is not confined to disabled individuals; able bodied people who possess a poor sense of direction may also benefit from virtual exploration. Kozlowski and Bryant (1977) concluded that for people to show a good sense of direction it was necessary for them (a) to make a conscious effort to orientate themselves, and (b) to provide them with repeated exposure to the test environment. Clearly, both of these requirements can be met with ease and safety using virtual environments.

The studies outlined in this thesis allowed physically disabled children to use simulations as a means of autonomously exploring whole environments and thus improving their spatial knowledge.

1.9 Summary

This chapter has illustrated the different orientation strategies that can be employed by animals and humans. The essential role of locomotion in gaining spatial knowledge has been discussed. Lack of autonomous exploration due to physical disabilities, that limit independent mobility, may underpin the difficulty that many disabled children find in forming effective, flexible internal maps with which to navigate in familiar or new environments. It has been shown that it is essential to construct tasks carefully to tap into the navigational strategy used in each case. In the following studies the aim is
to gain information on the formation of cognitive maps by using simulated environments that possess many of the characteristics of real environments (visual flow, detail, a frontal view). A range of spatial tests was used, including pointing tasks which were completed using the same medium in which exploration took place, thus eliminating some of the problems associated with drawing and modelling tasks.
Chapter 2

Virtual Reality: Definitions and Applications

2.1 Introduction

The previous chapter discussed cognitive mapping and the particular problems encountered by the disabled child. This chapter will outline virtual environment technology, its advantages and drawbacks, and how it is particularly suited to enabling the disabled child. Thus the possibility is raised that the spatial difficulties outlined in chapter 1 may possibly be ameliorated by 3D simulation technology.

2.2 Virtual Reality (VR) and Virtual Environments

"There are probably as many definitions for virtual reality as there are people in the field!" (Kalawsky, 1993, p.7). Virtual reality is a term that has been embraced by the press. In fact, 'virtual reality' is rather misleading as it is an oxymoron. The 'virtual' part is true, in that virtual optical images are being created, but the 'reality' part is rather dubious! Many authors prefer to replace the term 'virtual reality' with 'virtual environments.'

Virtual environments (VE's) have as their core the simulation by computer of three dimensional space. The first defining feature of VE’s is that they can be explored in real time with similar freedom to real world exploration. The second defining feature is that the user may interact with objects and events in the simulation. Although
shapes are rendered on a flat screen they are based on 3D data sets which describe their position in relation to the user’s viewpoint. Therefore as a user moves through a virtual environment the scenery and objects change with each step taken, just as they do in a real environment.

“We know how useful it is to walk through a building rather than view a series of photographs. We know that by holding an object and turning it in our hands, we gain insight and understanding into its structure. Being able to perform the same actions at a virtual level brings similar benefits: however, in the virtual domain the environment, be it a building or an object, is open to further design” (Earnshaw and Vince, 1995, p.xxi).

VE’s consist of three-dimensional, interactive, computer generated worlds, running in real time. Often, interacting with these worlds provides a feeling of “presence” as every response has a consequence, and the egocentric viewpoint gives the illusion of looking from ‘within’ the virtual world. Hamill (1994) states that “effective subjective immersion gives one the sense of being there, interacting directly with the simulated environment and the objects and events in it, despite being physically remote from the virtual space” (p.144).

Virtual reality can be experienced in a number of different ways. With desk top VR three dimensional environments are viewed on an ordinary computer monitor, the monitor acting as a window onto the virtual world. Movement is controlled either using the keyboard, a joystick or a spaceball (a ball that moves the viewpoint in any
direction in response to a small force). Sound is usually presented via external loud
speakers. The use of a specially designed lightweight pair of spectacles enables a true
stereoscopic image to be produced on a computer monitor. On the computer monitor
two views of the environment are rapidly alternated on the same screen: these views
are drawn from different eye perspectives. The spectacles have shutters in the lenses.
As these shutters open and close in synchrony with the two images on the screen, each
eye sees just one view. The user experiences an effective stereoscopic image (Wilson,
Foreman and Stanton, in press).

Immersion VR is achieved via a helmet-mounted display (HMD). The HMD may
contain one or two screens on which the VE is presented. Where two screens render
the same scene from a disparate view to match the individual viewpoint of each eye, a
stereoscopic image is created. A tracking system is used to update the view on the
screen in synchrony with movements of the user’s head, thus creating the illusion that
the user is looking around within a real space. Movement can also be controlled via
the keyboard or joystick. Sound is presented through headphones inside the HMD. It
is possible to use 3D sound systems, which allow users to gain directional information
from an auditory and/or visual display (Wenzel, 1991).

Virtual environments can also be projected onto large screens. A particularly
advanced system where the environment is projected onto three walls and the floor is
called the CAVE (Cruz-Neira, Sandin and DeFanti, 1993). When the user wears a pair
of Stereo View LCD shutter glasses, the projected environment fills the room and
surrounds the user. Users can walk around the virtual objects, and the fact that they can see their own bodies, enhances the sense of presence in this virtual environment.

Researchers aim to design interfaces exploiting skills that the user already possesses in order to make interaction with the computer more like interaction with the real world. Eye tracking techniques have been used rather than conventional interfaces (mouse, keyboard). A basic eye tracking device consists of two elements: a camera which observes the eyeball; and a soft infrared light that highlights the portion of the eye (for example, the boundary between the sclera (the white of the eye) and the iris) that is to be tracked. These devices can be attached to a headband. The eye tracker records the angle of the user’s eye in relation to their head. A separate tracker records the orientation of the head. These results combine to give the line of gaze in physical space. Using an HMD the head, eyetracker and display move in synchrony. Eyetracking has many potential applications. For instance, to enable interaction in situations when hands are already in use (an airline pilot). Also, for quadriplegic individuals who can move their eyes effectively, but are unable to use other computer input devices. As their ability to use other input devices is so limited, the eye movement interface, even in its early stages of development, provides significant benefit (Jakob, 1995).

Data gloves and data suits may be used to allow interaction by more natural movement. The data glove has fibre optic cables along its surface. As the user moves their hand, their joints bend, causing the fibers to bend, this angular movement is recorded by sensors. The computer receives these recordings and calculates the angle.
Thus any movement by the hand is imitated, in real time, by a virtual hand on the screen. The glove allows the manipulation of simulated objects, however the majority of these gloves do not provide any tactile feedback. The datasuit is a full body suit also fitted with fiber optic sensors (Greenleaf, 1992). Work is underway to produce haptic feedback in virtual environments. Johnson and Cutt (1991) describe work on tactile sensation, in order to gain shape and texture information, tactile sensors are used that press against the skin in time-varying patterns, and Brooks (1990) has produced force feedback by using electric motors that resist hand and arm motion. Brooks found that for a manipulation task, force feedback information produced an improvement in performance over a visual display (also see Huang, Boulic, Thalmann and Thalmann, 1995, for work on grasping). Treadmills have been used to portray motion in the virtual environment (Wickens and Baker, 1995).

All these new technologies increase the interactivity of the virtual environment. Sutherland (1968) stated that the challenge was to make the virtual world look, act, sound and feel real. The aims of VR are often deemed to be to provide a substitute for the real world. However for many applications this is not the case, and the user does not need to be completely deceived in order to benefit. For example in the present studies, our aim is to provide children with physical disabilities an opportunity to repeatedly explore entire environments in safety. They need to be free to manipulate the world autonomously, using an appropriate input device. Importantly, they must enjoy the experience so that they gain confidence and hopefully a useful degree of spatial knowledge that will transfer to real world situations. These aims can all be realised using relatively simple VE’s. All of the environments used in the present
studies were created by the experimenter using virtual reality authoring software, as described below, and were presented on a desktop system.

2.3 The construction of virtual environments

Superscape Virtual Reality Toolkit consists of three components: a shape editor, a world editor and a visualiser. Most operations can be carried out by ‘point and click’ mouse operations, supported by a pull down menu system.

Objects are created within the shape editor. Points are plotted in three dimensions. These points are then joined to create facets (planes). A number of facets are combined to form an object. Facets can be coloured, duplicated, transformed, rotated, minimised or maximised, animated, named and once the object is completed, stored as a whole.

Each object is then transferred into the world editor. The world editor provides the simulated space into which the objects can be positioned. Within the world editor objects are, grouped, positioned, resized and coloured. Individual shapes can be animated or made moveable. For example, a car can be controllable by a joystick and driven around the virtual environment. Sounds can be incorporated, for instance telephones may ring, or car horns can beep. Distancing is a process that allows quicker processing and faster updating by substituting a less detailed object by a more detailed version as you move nearer. This is realistic as the nearer you move to an object in the real world, the clearer the detail of the given object becomes. Collision
detection can be used in order to prevent the user moving through walls and objects and objects passing through each other. SCL (Superscape Control Language) is a C-like programme language that can be used to control movement, animation, lighting, distancing and the artificial intelligence of objects. Several viewpoints can be programmed, so that with the touch of a key a user can be transported to a particular location within the environment. In some of the environments used in the present experiments (see the Ash Field school simulation in Chapter four) when the user clicks on a particular door, this activates a programme that transfers the viewpoint directly to a new environment; this allows quicker processing, but does not affect the continuity of the environment. It appears as though a door has opened into a different room, and the user is unaware of the change in environment involved.

The final component, the visualiser, is used to display the completed virtual world. The visualiser allows the user to view, interact with and move around the completed VE but does not allow alteration of the environment variables other than minor refinements such as adjusting the movement step size.

2.4 The advantages of virtual environments for training

Virtual environments are potential useful media for training spatial skills for two reasons. Interactions with VE’s reproduce similar visual-spatial characteristics to interactions with the real world, and they can preserve the link between motor actions and their perceived effects (Regian, Shebilske and Monk, 1992). This may be primarily due to the three dimensionality of the display, which provides all of the
transformations in the visual appearances of objects that would accompany real
movements in space. In Gibson’s (1979) terms, the optical flow patterns that would be
experienced in the course of real movements are maintained in the displayed
environment. Gibson (1966) has argued that this optical flow provides two types of
information: about the layout of the environment, and about the movement of the
individual in relation to environmental objects, and thus it it hardly surprising that
participants seem to treat virtual environments as possessing at least some of the
attributes of real environments. For experimental purposes, such environments possess
a high degree of flexibility. The experimenter has complete control over the content of
the perceived world. These features make virtual environments particularly suitable
for research in spatial cognition, including the identification and remediation of spatial
deficits in disabled children. Regian et al (1992) suggest that training in VE’s may
improve the problem of inert knowledge. Inert knowledge is information learned in
the classroom but not applied in a real world situation even though it is relevant.

In the last chapter the problems of measuring children’s cognitive maps was
discussed. Even when models rather than map-drawing are used to assess cognitive
maps, problems are encountered. For example in Herman and Siegel’s (1978) study
children “were like giants in a miniature world.” If we are to tap into the formation of
internal representations of space we need to create more subjectively appropriate
situations. VR enables assessment of the internal spatial representations within the
same mode as they were acquired. A user explores a VE and then can be tested on
their spatial knowledge within this same environment using pointing tasks or route
tests. Siegel (1981) makes the point that a cognitive map is a representation of
experience, whereas an external expression is a re-representation and thus two levels removed from actual spatial activity. Thus Mohl (1981) suggests that the internal representation and the external expression which individuals form of an environment imply different contents and behaviour. Virtual Reality allows the testing of cognitive maps as they would be used naturally within the real world rather than via the rather abstract methods of drawing maps or creating models. It seems to be the next best option to testing in a real world situation, and has the advantage of being easily adaptable, allows repeated viewing, and provides tight control of cues. VE’s do not contain the unpredictability of the real world, unless this is necessary, and then it can be programmed into the environment.

Playing video games has been linked to the development of better spatial skills (Gagnon, 1985), using computer games has improved spatial knowledge (McClurg and Chaille, 1987) and computer games have been linked to cognitive rehabilitation (Larose, Gagnon, Ferland and Pepin, 1989). Therefore it would not be surprising if exploring environments on a computer, with the added advantage of the three-dimensionality and interactivity of virtual reality, was found to improve spatial learning.

Virtual environments are superior to maps as navigational aids, as they allow navigation through the environment viewing from an egocentric viewpoint and thus enabling an orientation free representation of space to be created (Tlauka and Wilson, 1996). (The orientation specificity of learning from maps was discussed in the previous chapter).
Virtual environments are valuable when individuals need to understand and interact with environments on a scale that 2-D interaction techniques can not accommodate. These are environments that are complex and large scale. Within a virtual world, information that may be distracting the user, causing an information overload, can be manipulated in an attempt to help the user create a more efficient cognitive map of the environment (Stytz, Hobbs, Kunz, Soltz and Wilson, 1995). As the frame of reference in virtual environments is egocentric rather than map-like, this bypasses translating a 2-D representation into a 3-D representation, and thus decreases the cognitive load that has to be applied to learning the information, and may benefit training (Regian, Shebilske and Monk, 1993).

There are numerous reasons why virtual environments are particularly suitable for the training of skills in individuals with mobility problems, for instance, they allow learning to take place without the danger of injury (Mohl, 1981; Wilson, Foreman and Stanton, 1997). In addition they allow rehearsal and repetition of movements and activities that would be impossible to repeat in a real environment. Often, in order to acquire accurate spatial knowledge, it is necessary to travel around an environment repeatedly and at one’s own pace until the desired level of skill or information is achieved (Kalawsky, 1996). The real world contains a rich variety of cues which make it impossible to reproduce the exact situation twice. VR allows complete control over what the user sees (Mohl, 1981). The almost limitless flexibility of virtual environments means that they can be adapted and modified to suit the needs of individuals. While disabled individuals might be limited in their interaction with the
real world, interactivity with virtual worlds can be ensured via the use of input devices that are tailored to the abilities of the particular user while accommodating their limitations. Inefficient locomotion may inhibit development in the disabled child due to drained energy and the attention needed to move successfully around the environment. All attention may be concentrated on the goal and the child may not have the resources to attend to the environment as well (Campos et al., 1982). In a virtual environment all attention can be concentrated on the task in hand. People tend to learn faster by ‘doing,’ and VR allows a high level of interactivity (Kalawsky, 1996).

Thus, for disabled users, virtual environments can allow autonomous self-directed activity (Cromby, Standen and Brown, 1996a; Wilson, Foreman and Stanton, 1997), which in turn can improve confidence in a child whose normal activity may be restricted, and who might always have been accompanied in the course of real world exploration.

2.5 Selection of apparatus and limitations

There is some debate in the literature on virtual reality as to whether it is advisable to use desk-top VR, in which the user views the environment on a computer monitor, or head-mounted displays, in which the environment is viewed via a screen or screens located in a head-immersion helmet. Ruddle, Randall, Payne and Jones (1996) tested two groups of participants’ ability to learn the layout of two large scale environments, one group using a desktop system and the other group using a headmounted display.
They found that participants navigated more quickly around the environment and gained a better sense of straight line distance when using a HMD. However they found no difference between distance travelled and accuracy when estimating directions between the two groups.

Desk-top VR was adopted in the present studies for a variety of practical reasons. In health and safety terms, it has been found that some individuals experience nausea, dizziness and visual problems when using head-mounted displays (Mon-Williams, Wann and Rushton 1993; Regan and Price 1994), although in other studies these effects have been found to be small (Foreman, unpublished data). Regan and Ramsey (1996) have reported the effectiveness of hyoscine (an anti-motion-sickness drug) to be effective in reducing symptoms caused during immersion in a virtual world.

The advantages of desk-top systems are that they allow interaction via the use of a simple input device, such as a joystick or keyboard, and they require only a standard IBM 486 PC or clone, of the kind that schools may already use (see Cromby et al., 1996a). Although the environments that were created for the present studies were displayed on desk-top systems and provide almost exclusively visual stimulation, experience suggests that participants do successfully acquire a feeling of 'presence,' particularly when they are actively engaged in a task such as finding a route or locating a target place (Foreman and Wilson, 1995; Wilson, Foreman and Tlauka 1996).
However we cannot claim that virtual environments do not have their limitations. Virtual environments differ from real environments in a variety of ways. The user is not fully immersed when using a desktop system and can be distracted by real world stimuli. The “field of view” in the virtual environment is only as wide as the screen it is displayed on, typically with a maximum of 100 degrees. Due to the limited field of view there is a lack of peripheral vision that may be of importance when building up a representation of the environment. With a desktop system, movements are controlled by an abstract interface, such as a keyboard, mouse or spaceball (Ruddle et al., 1996). Eye movement is not normally used, thus to glance over your shoulder involves rotating your entire viewpoint.

There is also the problem of time delays. When a large amount of detail is built into a VE there will be delays in movement as the computer updates the viewpoint for the user’s position within the environment. (See Wickens and Baker, 1995, for a discussion of the limitations of VR as a navigational aid). When designing a virtual environment a balance between realism, computer memory and cognitive load must be maintained: for example high levels of visual reality increase time lags in updating the visual display, and thus they may increase effort and the necessary concentration span of the user. This dilemma was particularly apparent when creating Ash Field school (see Chapter 4).

The other crucial factor, particularly in the present studies, is that the only sense that is being targeted is vision. There is no physical movement, thus a lack of vestibular and kinaesthetic feedback in the virtual environment, which authors such as Siegel
and White (1975) have demonstrated to be integral in the formation of the cognitive map. However, it is possible to experience a high level of presence in a virtual environment without stimulating the whole sensory system (Barfield, Zeltzer, Sheridan and Slater, 1995b).

In the present studies it is also essential to bear in mind that some children may have spatial deficits due to brain damage. Damage to “spatial” neural structures (the frontal cortex, the hippocampus or the right posterior cortex) can result in spatial awareness and spatial memory problems. It is unlikely that any medium can compensate for such problems. However poor spatial knowledge in children with limited mobility has also been shown to be due to limited autonomy, being transported passively and lack of confidence; it is not limited to those with this particular brain damage (see Foreman and Wilson, 1995).

2.6 Applications

General applications

Teleoperation was the forerunner to virtual reality systems. Teleoperated systems involve control of a machine within an environment by a human operator who is in a remote position from that environment. This type of system emerged where there was a need to view and interact with environments from a distance, for example in space exploration. This method leads to a sense of telepresence. Telepresence refers to the feeling that the human operator is physically present at the remote environment due to
the high level of natural information received about this environment via the teleoperated system.

Virtual reality systems were originally created for use by the military, space and aviation industries who produced realistic vehicle simulators (aircraft, automobiles and ships). These VR systems proved to be valuable training devices (Baum, 1992). More recent applications such as the Distributed Simulation Internet (DSI) described by Stytz et al (1995) include "The Satellite Modeler" which displays satellite models in their orbits around the earth. This system was created in order to visualise the spatial relations between space vehicles. A "Synthetic Battlefield", which is a large scale, dynamic simulation, has been devised in order to train in battle situations. Virtual environments can be used to provide a user with direct manipulation capabilities in a remote or non visible place, for example a remote piloted vehicle (Gunderson, Smith and Abbott, 1996; McGovern, 1991), an undersea robot (McKinnon and Kruk, 1991) or navigating through a virtual database (Newby, 1992). Many original military designs have been adapted for the use of the disabled (see Gunderson et al, 1996).

However as the equipment has become cheaper, more advanced and more widely available, VR applications are being used in a diverse number of fields such as medicine, town planning, architecture, and design. It would be impossible to review every application, so just a few examples will be given (For a more extensive review see Barfield and Furness, 1995).
Augmented reality (AR), where the image viewed through the headset is overlayed onto the real world, has many medical applications. AR allows images to be superimposed onto the actual patient allowing a precise planning of surgical procedures (Barfield, Rosenberg and Lotens, 1995a). It is being used to view ultrasound images in three dimensions (Bajura, Fuchs and Ohbuchi, 1992) and also to visualise medical images of a patient's anatomy.

VR can be used to recreate places of historical interest that no longer exist, in order that we may gain a better insight into the past. For example, virtual versions of the Xian terra-cotta soldiers are being created, all with different expressions and original clothing designs (Thalmann, Pandzic and Moussaly, 1995). At the opposite end of the spectrum, Fujii, Imamura, Yasuda, Yokoi and Toriwaki (1995) are using a VR system for effective city planning in Japan, allowing visualisation of buildings and places before they are actually constructed.

Virtual environments can be used to rehearse critical actions in a safe environment ready to perform the same task, or procedure, in an unsafe real environment. For instance, practising emergency procedures in a variety of systems (Baum, 1992; Wilson et al, 1996). Obviously, effective transfer of training is essential if procedures are to be rehearsed in a virtual environment. Transfer of training will be expanded on further in this chapter and in chapter 4.

The different viewpoints and perspectives that VR enables, allows insight into the structure of an environment, such as combinations of molecules (Brooks, 1993). Colle
and Green (1996) describe a system where graphical simulations of the behavior of
virtual participants in a laboratory or field experiment have been used to introduce
psychology students to the research process!

Training

VR has been used to train wayfinding abilities. Ruddle, Payne and Jones (1997)
recreated the building used in Thorndyke and Hayes-Roth's (1982) study. Two groups
of participants learned their way around this one hundred and thirty five room virtual
environment. One group had nine route finding sessions and the other group learned
from a floor plan. Spatial knowledge was tested using distance and direction
estimations. The scores of those trained in the virtual environment and those of people
who worked in the real building were similar for euclidean distance and direction
estimates. However participants trained in the virtual environment had difficulty
estimating real distances. The authors suggest that absolute distance estimation may
be inherently difficult in a VE (see Chapter 4). Those who used the floor plan
performed as well as those who explored the real building.

Hunt, Arch and Roll (1987) used a simulation to teach elderly people about an
unknown building. They found that exploring the simulation was equally as effective
as visiting the real building in enabling confidence and efficient wayfinding and in
building up an internal representation of the building. Simulations were suggested as a
means of familiarising the elderly with retirement homes before they were relocated.
Research into navigation techniques in a virtual environment.

Billinghurst and Weghorst (1995) examined how people form cognitive maps of virtual environments as they believe that this is essential for optimum virtual world design. They found that participants who reported feeling orientated within the virtual environment produced better sketch maps. Therefore they maintain that sketch map accuracy can be used as an external indicator of orientation and spatial knowledge. This is an interesting finding considering the controversy over the use of sketch maps as indicators of spatial knowledge outlined in Chapter one.

As stated in Chapter one, landmarks are integral in the formation of an internal representation of one's environment. The importance of landmarks in route-learning has been investigated in a virtual environment (Tlauka and Wilson, 1994). A virtual environment enabled landmark strategies to be examined in an environment with no natural cues, only those manipulated by the experimenter. A first experiment contained a landmark and a non-landmark condition. No difference in performance was found between the two groups. It was hypothesised that those participants in the non-landmark condition were learning a list of correct left/right decisions in order to complete the task. When the latter strategy was suppressed by introducing a back-counting task, which was carried out while learning the route, participants in the landmark condition performed significantly more accurately than the those in the non-landmark group. Landmarks proved to be just one of many strategies used to remember routes.
It is essential to find the optimum way to present information in a virtual environment. Many studies have shown that self-directed activity is important. Standen and Low (1996) have found that virtual environments actually promote self-directed learning, but is it necessary for the subject to actively explore, or is it sufficient to actively direct another individual, or purely watch another in order to gain spatial information? This is an important consideration, as many physically disabled children, if they are not equipped with appropriate input devices, may at present only be able to passively use virtual environments (they may require others to move their viewpoint using the keys or joystick). Peruch, Vercher and Gauthier (1995) found that participants performed better on spatial tasks when active rather than passive. However, Wilson, Foreman, Gillett and Stanton (in press) found that both active and passive participants gained similar levels of spatial knowledge from virtual environments, whereas Attree, Brooks, Rose, Andrews, Leadbetter and Clifford (1996) found that active participation enhanced memory for spatial layout whereas passive observation enhanced object memory. Williams and Wickens (1993) found that active involvement or control within the virtual environment proved important in retaining a skill.

In the present studies maps are used as an indicator of spatial knowledge, but they are used in conjunction with other methods of measuring spatial skill such as pointing tasks and route tests, in order to provide a fuller picture and examine which method of measuring spatial skill is most appropriate. As the active-passive issue has yet to be resolved, all participants in the studies in this thesis actively explored the virtual environments using an appropriate interface.
Transfer of information from a virtual to a real environment.

If VR is to be used in training it is essential that the skills learned within a virtual environment transfer to the real world. Wilson et al (1996) have established that both able-bodied and physically disabled individuals can acquire spatial knowledge of a real building purely via exploration of an accurate virtual simulation. Cromby, Standen, Newman and Tasker (1996) demonstrated successful transfer of shopping skills from a virtual supermarket environment to a real equivalent by a group of students with severe learning difficulties.

Similar results have been reported when evaluating the ability of able-bodied participants to learn to navigate through a virtual office building (Regian et al. 1992; Witmer, Bailey and Knerr, 1995). Virtual experience may not be as effective as real exploration, but it does impart spatial information of a useful quality. Mohl (1981) used an optical video-disc based system under computer control, to create what he termed an "interactive movie map." This enabled users to explore two representations of Aspen, Colorado interactively. The first representation involves travelling through the environment encountering real scenes which had been filmed in Aspen. Secondly the user can fly above aerial views of the same environment. Mohl found that after movie map training participants displayed superior wayfinding ability in the real setting. Inman, Loge and Leavens (1997) used a series of VE’s to teach children to control motorized wheelchairs. The environments ranged from a bland world used to teach basic commands to a more complex environment (modelled on a real street)
which enabled children to practice crossing the road. They found that driving skills improved as function of the time spent training in the VE's (see also Kuhn, 1994).

Some skills transfer better than others. In Regian et al's study participants learned both spatial-procedural tasks and spatial navigational skills within the virtual environment, yet in another study, Kozak, Hancock, Arthur and Chrysler (1993) failed to show transfer of skill from a virtual environment to a real environment for a pick and place task. They suggest that perhaps the cognitive load (the demands) of learning the task in a virtual environment were too high. There is also the chance that the task was too simple!

The possibility of negative transfer must not be overlooked. Skills learned in one setting may actually inhibit performance in a different setting (Wickens, 1992). Research has shown that when two situations have similar stimulus components but require quite different responses, transfer may be negative, or what Singley and Anderson (1989) have called “the positive transfer of inappropriate responses.” When designing environments in which skills are to be learned in the hope of transfer to a real world setting, it is important to examine differences that may produce incorrect responses or strategies. The issue of negative transfer is crucial in two areas. Firstly, it is important for the operator using two different real systems. For example concern has been raised about the number of different aircraft a pilot may fly because differences between cockpit displays can result in errors (Braune, 1989). Secondly, negative transfer must be considered when information is to be transfered from a training situation to a real equivalent. ‘Simularity’ of virtual and real environments
may not be 'the key' to transfer. Differences between two environments may not be
detrimental if a simulation enhances features which are most relevant to the task that
is to be carried out. "Two systems may be considerably different in their display
characteristics but can involve positive transfer if there is an identity in the response
elements" (Wickens, 1992).

The issue of transfer of training will be examined in some detail in chapter 4.

Virtual Reality applications for disability

(a) Visual deficits

The simulation based research reported in this thesis relies on the visual sense,
however work has been carried out using VR for the visually impaired and the blind.
Zwern and Goodrich (1996) designed enlarged screens for the visually impaired that
could be viewed through a head mounted display (HMD). Lumbreras, Barcia and
Sanchez (1996) created a 3-D sound system that can be listened to through
headphones and used to manipulate localized sounds that can serve as graphical user
interfaces (also see Keating, 1996, for 3-D sound environments for the blind). Probert,
Lee and Kao (1996) have created advanced interfaces for navigation for the blind.
Their 'sonar belt' uses ultrasound to provide low level directional information
allowing the blind to move through the environment without the use of a stick.
Information is transmitted to the user by vibrations from the belt and has the
advantage that it leaves the users' hands free. They are also working on a frequency
modulated sonar which would provide information on features and landmarks, so that
the user would be able to build up a more detailed representation of their surroundings. Urdang and Stuart (1992) describe a possible system where landmarks have radio beacons which transmit audio signals of their names. The user could locate more than one beacon and thus be able to triangulate in order to orientate themselves. However this would need to be an augmented reality system as users would not want to be cut off from other real world sounds.

(b) Auditory deficits

For the deaf, Vanplew (1996) has developed a portable device that converts sign language to speech. As many hearing people cannot sign, this will allow better communication between deaf and hearing people (see also Harwin and Foulds, 1996, for a machine that recognises and interprets American Sign Language). Brown and Wilson (1995) have created an environment to teach Makaton sign language, where a virtual mannequin performs the hand signs and a virtual scene of objects provides an illustration of the sign.

(c) Other senses

Touch and force feedback are not well developed in most VR systems for the disabled. Earlier on in this chapter general research on these senses was discussed. However, Zerkus, Becker, Ward and Halvorsen (1992) have described a displayed temperature sensing system that transmits temperature information to humans and is being used in prosthetics research. Temperature sensors are placed in the prosthetic limb and then a displaced sensing system transmits the feeling of temperature to another part of the body that can sense the feeling.
Applications to improve autonomy and control

Applications have been designed in order to give the disabled increased control of their environments. Gunderson et al (1996) have designed a system where a remote controller can assist a wheelchair user in a difficult navigational situation, by taking control of navigation and steering of the real wheelchair in the real world. This could give disabled people the confidence to go out alone knowing that if they encountered any difficulties, got lost or even tired, they could call on the remote user to navigate and take them home. Mowafy and Pollack (1995) developed a virtual bus ride to train people with physical and cognitive disabilities to use public transport independently. First they simulated the routes between the students’ home and town and town to the University. Then they taught the participants to look out for landmarks and where to get off the bus.

Augmented reality (where the image on the headset is transposed onto the real world) could be used to allow physically disabled users to operate electrical devices in their house just by looking at them (Hammond, Sharkey and Foster, 1996). Davies and Eriksson (1996) used virtual environments in order to allow simple visualisation of environments that were to be adapted for the disabled (see also Trimble, Morris and Crandell, 1992). Roberts, Wood and Gibbens (1996) have designed environments where people can socialise in order to defeat the isolation that many people with disabilities report. They describe a ‘virtual meeting place,’ where people can interact, and overcome the physical problems of mobility and communication. To enable more advanced interaction they are looking into ways of expressing emotion in a VE
context. Gilden (1991) suggests using VR to enable able-bodied individuals to experience disability so that they can appreciate the problems encountered.

(e) Assistive devices and technology

Hollands and Trowbridge (1996) have designed a training tool for arthroscopic treatment of knee disabilities. Arthroscopy is a technique that involves less intrusion and faster recovery rates than surgery. It is a precise art, and the skills required are different to those of open surgery, thus VR provides a relatively cheap and effective system by which to teach this technique. Rosen (1991) describes a surgical simulation, where a surgeon can perform life-like operations on an electronic cadaver in a “virtual” operating theatre. He describes various applications that have already begun, for example, a model of a hand that allows realistic tendon transfers for patients with nervous palsy. Harwin and Rahman (1996) have devised assistive telerobotic devices to give added strength and range of movement for the physically disabled. For example, they have created a mobile arm support for people with conditions such as muscular dystrophy who experience decreased muscle strength.

Magnusson (1996) has suggested the use of touchscreens to enable those with aphasia easier access to the internet. Greenleaf (1992) has created “The Virtual Receptionist,” a system developed for people with cerebral palsy, to enable them to work as receptionists, using a data glove to work a computer-driven telephone-answering programme. Instance, Spinner and Howarth (1996) have designed an on screen keyboard as a general input device which is operated by eye gaze for those with motor impairments. This keyboard manipulates keyboard and mouse, supports interaction
with graphical user interfaces such as scroll lists and dialogue boxes, compensates for inaccuracies in eye-based control and also allows adaption of the keyboard to suit the task or user. The aim being to allow access to the same software product that an able bodied user has, via a different interface.

(f) Rehabilitation

Weghorst (1997) used virtual environments to train people with Parkinson’s Disease to walk in relation to virtual outlines. Using augmented reality a grid like pattern was overlayed onto the real world via a HMD. With the use of this grid structure, sufferers found it much easier to control their gait (see also Emmett, 1994). Strickland, Marcus, Hogan, Mesibov and McAllister (1995) have used VR as a learning aid for autistic children. Harwin and Foulds (1996) describe an interface designed to teach physically disabled children about physical laws such as how a ball bounces. AIDS prevention for people with mental retardation has been provided by means of an interactive videodisc, where the user can choose a guide (who may be a doctor or someone with knowledge about AIDS) to take them through the database (Rose, 1990). Rose (1992) describes a ‘virtual discussion group’ for parents and children to supplement counselling on children's disabilities.

Virtual reality is starting to be used in the rehabilitation of people who have suffered traumatic brain injury (see Rose, 1996, for a review). Rushton, Coles and Wann (1996) comment on how VR tests are potentially useful in the rehabilitation of unilateral visual neglect. Following a stroke many patients suffer from unilateral visual neglect, which is the “disregard of objects in the space contra-lateral (opposite)
to the major cerebral damage” (Rushton et al., 1996, p.227). Classic signs of neglect are just shaving one half of the face or eating food on one side of the plate. VE’s could be useful in the rehabilitation process, as they offer a degree of ecological validity, allowing the rehearsal and training of tasks similar to those attempted everyday in real life. Wann (1996) states that the novelty of VE’s could provide a strong motivational factor. Further, the ability to safely make errors, interact with and explore an environment may aid the ability to relearn motor skills. Johnson, Rushton and Shaw (1996) describe studies underway to combine the positive effects of exercise and enriched environments to aid rehabilitation after brain injury. A VR display is coupled to an exercise bike so that in the safety of an indoor environment participants can gain exercise and in order to maintain their motivation and to improve their motor skills, they complete tasks in the virtual environment.

Virtual reality has also been used to treat various phobias, such as acrophobia (Rothbaum, Hodges, Kooper and Opdyke, 1995), and fear of flying (Rothbaum, Hodges, Watson and Kessler, 1996). For a review of VR and phobia treatments see Kirkby (1996).

2.7 Summary

Research using VE’s has thus stemmed from the military, space and aviation industries into areas such as education, medicine, building design and various applications for those with disabilities. Although VE’s appear to have great potential in training and rehabilitation, the outlined limitations of the technology must be kept
in mind. In terms of disability, research spans all the senses, with the aim of improving autonomy and control, developing assistive devices, and rehabilitation. However much of the research in these areas is still in the planning stage, with few empirical results currently available.

2.8 Aims of this thesis

“Some tasks may be uniquely suited to virtual representation, while others may not be effectively performed in such environments” (Stanney, 1995, p.28).

The following studies reported in this thesis aim to investigate whether, and to what extent, three-dimensional simulations may be useful for investigating, and helping to improve, the spatial skills of physically disabled children. The spatial knowledge of groups of children with physical disabilities was assessed using virtual environments, transfer of training from virtual environments to their real equivalents was examined, and the effects of repeated exposure to virtual environments are reported.
3.1 Introduction

There are few studies looking at the development of internal spatial representations in disabled children (Foreman et al., 1989b; Simms 1987). Neither of these studies included a shortcut task. The ability to take shortcuts demonstrates the formation of an effective internal representation of space (Chapuis, Durup and Thinus-Blanc, 1987; Chapuis and Varlet, 1987; Pick and Lockman, 1981; Poucet, 1985; Shepard, 1933).

The best controlled studies looking at the formation of the internal representation of spatial relationship have been carried out with animals. Shortcut and detour studies have been used extensively to test the spatial abilities of different species of animal (see Chapuis et al., 1987; Maier, 1932; Poucet, 1985; Shepard, 1933). Some of these tasks can only be completed successfully if the animal is forming some kind of internal spatial cognitive map. Simply remembering prior routes will not enable the animal to make the correct response.

"Once spatial relationships are established between places and charted on a representation, there is more than one pathway, like that which is usually taken, which can link them together. The orientation process does not rely on rigid routes but on the precise localization of the places concerned. It follows from this that if the possibility
of a shorter route is offered, pointing in the direction of the goal, it is chosen without hesitation” (Thinus-Blanc, 1996, p.87).

Chapuis, Durup and Thinus-Blanc (1987) tested golden hamsters on a shortcut task after directed exploration. All the hamsters explored two separate subspaces each comprising two tables linked by a runway, but only the experimental group explored an additional runway connecting these two subspaces. Experimental and control groups were then given a shortcut test. They had to go from a table in one subspace to a table in the other subspace. The adoption of the shortest routes required the use of runways that the animal had not explored before. The experimental group, by comparison with the control group, chose the shortcut significantly more often, reflecting the creation of an internal map of the environment that allowed the animal to choose a runway that led directly to the goal table, despite the fact that it had not been previously experienced.

Equivalent human studies are difficult to arrange because a large scale environment with appropriate properties cannot easily be constructed and maintained. Real environments contain many cues that are difficult to control and the environment rarely remains constant. However simulations allow the essential features of animal paradigms to be reproduced for use with humans, creating a large scale environment with none of the distractions of a real environment. VE’s have been used to assess cognitive abilities, looking at transfer of spatial information (Wilson, Foreman and Tlauka, 1996) and examining the role of landmarks in learning a route (Tlauka and Wilson, 1994).
In the present series of studies the experimental environment used by Chapuis et al (1987) was created as a 3-D simulation and this was used to test human participants on the hamster task. The original design and procedure were followed as closely as practically possible. The aim of the following experiments was to examine participants' abilities to complete a shortcut task after exploration of selected sections of the environment. Just as with hamsters, to solve the problem efficiently it is necessary for participants to form a 'link' between the explored spaces, and thus their ability to take shortcuts would indicate that they had also formed an internal 'map' representation of the experimental space.

In many shortcut experiments that claim to illustrate the use of a cognitive map, cues have not been adequately controlled (see Morris, 1981; Olton, 1978). In order to be sure about the animals' use of spatial cues in making judgements, it is necessary to positively identify (and manipulate) these cues. If a cue is closely associated with a goal then a simple directional guidance strategy can be used and no internal representations are necessary for navigation. Chapuis et al (1987) argue that this could not have been the case in their study, as the control group failed to take the shortcut on the first test. Had the animals associated cues with the starting point and the goal table they would all have completed the shortcut in the first test. However, animals that had explored the link chose the shortcut significantly more often than the controls, implying the necessary use of an internal representation of space to solve the task.
In the present section the first three experiments looked at the type of cue or cues needed for successful spatial learning performance. It was important to examine this issue since Restle (1957) showed that what is learned may depend on particular features of the situation, such as the richness of cues. If an environment is relatively uncued, response learning may predominate, whereas if the environment is rich in cues a cognitive map may be formed. As the present study was especially concerned with the formation of internal representations of space, it was necessary to create an environment that was conducive to the latter form of learning. Experiment 4 tested whether the simulation was a successful adaption of Chapuis et al's original test environment and if the task was sensitive to spatial learning effects. Experiment 5 examined whether disabled children could complete the shortcut using the cues that were identified as essential in the earlier experiments in the series.
3.2 Experiment 1

Method

Participants

These were 24 pupils from a Leicester secondary school, 14 were male and 10 were female. They had a mean age of 13.5 years (SD: 0.51). Participants were selected by their teachers as those of an average intelligence with no known learning or behavioural difficulties. All children had vision that was normal or corrected to normal.

Design

Each child explored four virtual rooms A, B, C and D in a single environment, via linking pathways. Figure 1a illustrates the layout of environment. The participant explored three of the outer pathways on a set route determined by the experimenter. The fourth outer pathway and the inner pathway were never explored, and served as shortcuts for later testing. The routes taken during exploration were counterbalanced, creating four variations: a) AB, CD, AD, shortcut CB; b) AB, CD, BC, shortcut AD; c) AD, BC, AB, shortcut CD; and d) AD, BC, CD, shortcut AB. The independent variable was the pathways visited during exploration. The dependent variable was the participants’ choice of path when asked to find a particular room.
Figure 1a

Plan view of the shortcut test environment
Apparatus

The experimental environments were created using Superscape Virtual Reality Toolkit and were presented on an Intel Pentium 90 with SVGA graphics, displayed on a 14 inch monitor. The environments were based on those created by Chapuis et al. (1987). Four rooms, A, B, C and D were linked by five pathways. Each room was coloured differently and contained one or more objects. The interior of room A was red, and contained a computer. Room B was blue and contained some audio speakers and had a chequered floor. Room C was yellow and housed an animated dragonfly and an insect. Room D was green with an animated digital sign with the word ‘welcome’ displayed. Each room was identical when observed from the outside, each appearing white with the word “ENTRANCE” printed on the door. The rooms were 90000 by 70000 units with a height of 30600. The viewpoint was set at 18000. As the average human height is approximately 1.6 metres, this translates to subjective dimensions of approximately 8 x 6.6 x 2.7 metres. The pathways differed only in length (see figure 1a for measurements). The inside of each room was not visible until the participant moved very close to the entrance, when the automatic doors were programmed to open. During exploration, “no-entry” barriers were used to signal the paths which were not available. To move from room to room instantly for testing, and to save the participant having to wait for the environment to be reloaded numerous times, each room was programmed such that when the experimenter clicked with the mouse on a particular wall the viewpoint was transferred immediately to another room.
Four cues were placed around the outside of the environment, beyond the rooms and pathways. Cues were placed between rooms, such that none of the cues was directly associated with any one room. The cues consisted of a dark red cross, a green pyramid, a grey scaffold tower and a brown inverted V shape, which were 121500, 97500, 121500 and 67500 units high respectively and approximately 1387000 units from the centre of the environment. A response was defined as crossing the halfway mark on an arm. The software was programmed to record responses automatically.

A practice environment was created so that each participant could familiarise themselves with moving around using the keys, and the novelty of this type of environment. The practice environment consisted of two rooms joined by a pathway. Another pathway was also present in the environment, leading away from one of the rooms, but with a no-entry barrier on it. The rooms were white with the word “ENTRANCE” written on them. They were empty inside. The participant was first asked to practice moving along the pathway using the keyboard arrow keys. They were told not to pass through the barrier. (If they tried to do so, the program prevented them from proceeding). If they veered from the pathway, they had to move straight back on to it. When the participant appeared proficient at moving around in this environment and stated they were ready to proceed, the experimental environment was loaded.
**Procedure**

Each participant was tested individually. The initial viewpoint in the environment was in the centre facing the exterior of one of the four rooms (the room faced was alternated). This position is marked with an X on figure 1a. The experimenter rotated the viewpoint through 360 degrees, pointing out the four rooms and the distal cues, and suggested that the participants may want to use the cues to help them complete the task. The participants were told that their task was to explore the rooms, and that they must try to remember the position of each room in order to complete shortcut tasks later when all the barriers were removed. They were told to feel free to stop and look around at any time. Then, in the counterbalanced arrangement described in the design section, each participant was placed in one room (for example, A), shown the contents of that room, and then transported to another room (B) and asked to find room A again. When they had found room A (there was only one route they could take A-B, as the other paths were blocked by no-entry barriers) they were asked to return to room B. The experimenter then transported them into room C. They were shown around, transported to room D and asked to find room C and then to return again to room D. Finally they were transported back to room A, then placed in room D, asked to find room A, and then return to room D. Note that the A-D link connected the two pathways previously explored. The barriers were always positioned so that only the correct route could be taken. (Note that ‘exploration’ was restricted as participants were only able to take experimenter determined paths.) The whole procedure of exploring the rooms was then repeated, in an identical fashion, to allow
the participant to concentrate on remembering the relative position of all the rooms, prior to the shortcut task.

For the test trial all the barriers were removed, and a counter was revealed at the bottom of the screen. The experimenter returned the participant to the centre of the environment again in order to refresh their memory for the cues. Then they were transported into the test room (C) and asked to find a room (B) taking the shortest route. Neither room had been visited by the participants in the third exploration phase (A-D). From the test room the participant had three paths to choose from: the shortcut (C-B), the diagonal (C-A) and the path with which they had had previous experience (C-D) (see Fig. 1a). The correct response was to follow the path C-B that the participant had not explored before. The participant was then asked to complete a second shortcut. They were transported back to the start room (C) and, if they had completed the first shortcut successfully, they were asked to find room A via the shortest route. If they had not been successful on the first trial they were asked again to take the shortest route to room B. This time, with a memory of the first choice, they only had a choice of two pathways. (No participant repeated the response that they had made on the first shortcut test). Finally, the experimenter asked the participant to describe the method that they had used to complete the task. Their comments were noted. The entire experiment took approximately twenty five minutes to complete.
Figure 1b

The percentage of children who chose the shortcut during the test trials
Results

Figure 1b illustrates the percentage of participants who chose the correct route (the shortcut) during the two test trials. On trial 1 participants chose the shortcut on 25% of occasions compared with the 33% expected by chance ($\chi^2 [1] = 0.39, p > 0.05$) and on trial 2, 79% did so, this time compared with 50% expected by chance, remembering that one path had been eliminated in the course of trial 1 ($\chi^2 [1] = 8.17, p < 0.05$). Results tables can be found in Appendix I.

Discussion

The results suggest that on the first trial participants were unable to complete the shortcut with better than chance accuracy, though the results for the shortcut on the second trial were significantly better than chance. Many participants commented that they had hardly noticed the cues during the first part of the experiment, if they had noticed them at all. No two cues could be seen simultaneously from any one viewpoint (in a single frame) and it was suspected that they were having difficulty connecting the environment as a whole. Perhaps this environment was too bland. As Restle (1957) suggested, people can resort to using guidance strategies in poorly cued environments, strategies that would be ineffective when choosing a shortcut.

Chapuis et al.'s (1987) original apparatus was surrounded by cues, since it was positioned within a standard experimental room. Therefore in order to replicate that
cue arrangement more closely in the simulated environment, Experiment 2 used an environment with continuous cues surrounding the apparatus.
3.3 Experiment 2

Introduction

Experiment 2 employed the same basic environment as Experiment 1, but incorporated an octagonal fence that surrounded the pathways, providing continuous cues rather than four individual cues. It was hypothesised that participants would be better able to use these cues in order to form an internal spatial representation of the environment and would thus be capable of successfully completing both shortcuts.

Method

Participants

These were 24 pupils from a Leicester secondary school, 12 were male and 12 were female. They had a mean age of 13 years (SD: 0.20). Participants were selected by their teachers as those of an average intelligence with no known learning or behavioural difficulties. All children had vision that was normal or corrected to normal.
Figure 2

The percentage of participants who chose the shortcut during the test trials

![Bar chart showing the percentage who chose the shortcut for Trial 1 and Trial 2]
Apparatus

This was identical to that in Experiment 1 except for the cues. The four cues used previously were replaced by an octagonal brown fence circling the experimental apparatus, which had a diameter of 3060000 units and a height of 411000 units. Eight distinctively coloured and designed shields were positioned at regular intervals on the fencing at mid height.

Design

As in Experiment 1.

Procedure

As in Experiment 1.

Results

Figure 2 illustrates the percentage of participants who chose the correct route (the shortcut) during the two test trials. On trial 1, participants chose the shortcut on 58% of occasions compared with the 33% expected by chance ($\chi^2 [1] = 6.75, p < 0.05$). However on trial 2, only 67% did so, compared with the 50% expected by chance ($\chi^2 [1] = 2.67, p > 0.05$). Results tables can be found in Appendix I.
Discussion

A statistically significant proportion of the participants selected the shortcut on trial one. However this was not the case for trial two. Although the results are consistent with the use of an internal representation to complete the first shortcut, the results of trial 2 do not support this hypothesis.

Analysis of participants reports suggest that the majority of the children only remembered a maximum of four cues. The size of these cues may also be a critical factor. Acredolo and Evans (1980) found that landmarks had to be very salient to compete with egocentric responding in the young child. Witmer et al (1995) suggested that the size of landmarks in virtual environments may be more critical than in the real world. The relatively low resolution of many virtual environment display devices reduces visual acuity. Although Witmer et al were mainly referring to immersion headsets, this factor could be particularly applicable to desktop systems due to the narrow field of view on an ordinary computer monitor, and the resulting lack of peripheral cues. Additionally, due to the novelty of the environment and the relatively short time with which the participants had to explore, it is likely that cues needed to be prominent. Therefore for the next experiment shortcut ability was investigated using the four cues from Experiment 1, but they were enlarged, so that in any one screen, two of the cues were always visible.
3.4 Experiment 3

Introduction

The four cues from the first study were enlarged so that there were always sections of at least two cues in each frame and these cues were extremely prominent. It was hypothesised that this cue formation would allow the child to form an effective internal map, enabling successful completion of the shortcut.

Method

Participants

These were 24 pupils from a Leicester secondary school, 8 were boys and 16 were girls. They had a mean age of 13.8 years (SD: 0.44). Participants were selected on the same criteria as the previous two studies.

Design

As in Experiments 1 and 2.
The percentage of participants who chose the shortcut during the test trials.
Apparatus

The fence was removed and the four cues used in Experiment 1 (the pyramid, the inverted V, the cross and the tower) were increased in size by a factor of 4 and positioned as in Experiment 1. The pyramid was coloured orange rather than green so that it was more prominent against the green background.

Procedure

As in Experiments 1 and 2.

Results

The results are displayed on figure 3. On trial 1, participants chose the shortcut on 58% of occasions compared with the 33% expected by chance ($\chi^2 [1] = 6.75, p < 0.05$) and on trial 2, 79% did so, compared with the 50% expected by chance ($\chi^2 [1] = 8.17, p < 0.05$). Results tables can be found in Appendix I.

Discussion

The results demonstrated that with the large cues a statistically significant number of fourteen year-old children could complete both the first and second shortcuts with greater than chance accuracy. From this we may infer that they had developed a
flexible, efficient internal spatial representation. The fact that two cues were visible within each frame appears to be an important, if not crucial factor in enabling the participants to complete the configuration of surrounding cues, and thus represent the environment as a whole. The results support the hypothesis that, with this cue arrangement, some form of internal cognitive map was successfully created, connecting the different rooms.

The majority of participants reported using at least two or three of the cues. However, four of the participants reported that they did not use any of the cues, but they successfully completed the shortcut. These participants had built up a picture of the layout of the environment "in their head" by deducing that the yellow and red rooms were opposite one another. As the blue room was to the left of the red room and the green room to the right, but the blue room was to the right of the yellow room and the green room was to the left, they reasoned that the yellow and red rooms were opposite one another. This is still a form of internal spatial map-like representation but it was formed independently of the distal cues. There were too few of these types of method of navigation reported for an analysis.

This experiment was successful in establishing the type of cues that must be incorporated into an experimental environment for successful completion of the shortcut task.
3.5 Experiment 4

Introduction

Experiments 1-3 provided information on the type of cue that was most effective in enabling the individuals to form an effective representation of the environment, and the type of cue formation that was ineffective. In Chapuis et al’s original study a control group also carried out the task. This group explored two unconnected runways but never had experience of a runway linking the two subspaces. This group, who proved to be much poorer at the task, illustrated the crucial role of the linking element in forming an internal representation of the whole environment. Thus in order to test that the paradigm was an effective measure of the creation of an internal map and was a successful adaption of Chapuis et al’s test environment the following study was carried out incorporating a control group. As this study was purely testing the strength of the paradigm, and not a particular population’s ability, undergraduates served as the participants, rather than children, as in the previous studies.
Method

Participants

These were 24 psychology undergraduates from the University of Leicester, 6 were males and 18 were females. They had a mean age of 21.8 years (SD: 6.16). They completed the experiment as part of their first year course requirement.

Design

The participants were randomly split into two groups of 12: a control group and an experimental group with 3 males and 9 females in each. Each participant explored rooms A, B, C and D via the linking pathways. The experimental group explored three of the outer pathways on a route that was predetermined by the experimenter. The control group only explored two of the outer pathways. As in the previous experiment the pathway not explored and the inner pathway served as shortcuts for the test. The routes taken during exploration were counterbalanced creating four conditions: a) AB, CD, (AD), shortcut CB; b) AB, CD, (BC), shortcut AD; c) AD, (BC), AB, shortcut CD; and d) AD, BC, (CD), shortcut AB (the routes in brackets were only taken by the experimental group and not the control group). The independent variable was the pathways visited during exploration, with two levels (either two paths explored, or three). The dependent variable was the participants' choice of path when asked to find a particular room.
Figure 4

The percentage of experimental and control groups who chose the shortcut during the test trials.
Apparatus

As in Experiment 3.

Procedure

As in Experiment 3, except that the control participants only explored two pathways and no linking pathway.

Results

Figure 4 illustrates the percentage of those in the experimental and control groups who chose the correct route (the shortcut) during the two test trials. For shortcut 1, 67% of the experimental group chose the correct path compared with 25% of the controls ($\chi^2 [1] = 4.20, p < 0.05$). For shortcut 2, 100% of the experimental group chose the correct route and 67% of the control group ($\chi^2 [1] = 4.80, p < 0.05$). Results tables can be found Appendix I.

Discussion

The experimental group performed significantly better than the control group on both shortcut tests. These results demonstrate the advantage gained by exploring the pathway that links the two areas. This linking element allows the participant to
integrate information about the environment as a whole. When the linking element is explored, spatial elements of the environment can be brought together to form an internal representation, which in turn allows the participant to orientate themselves from any position within the environment. Without exploring this linking pathway the environment is ‘disconnected’ and conceivably may even be envisaged as two completely separate places. This experiment demonstrates that the simulation paradigm developed here is a good measure of spatial ability. The results are in good agreement with those of Chapuis et al (1987) and suggest that this computer simulated environment is an effective replication of their original task.

Experiments 1-3 have investigated the important features of the external cue arrangement for spatial learning. The present experiment has shown that, with an optimal cue arrangement, the simulation task is sensitive to spatial learning effects, and provides good evidence of configural learning. These experiments have established a new and potentially important methodology for investigating spatial learning ability. One advantage of this paradigm over other spatial learning tasks is that it is active and dynamic but does not require great physical effort. In Experiment 5 this methodology is applied to an assessment of the spatial abilities of physically disabled children.
3.6 Experiment 5

Introduction

The few studies that have been carried out to date examining cognitive mapping skills have provided preliminary evidence that children with mobility limitations have difficulty forming effective cognitive spatial maps (Foreman et al., 1989b; Simms, 1987).

As outlined in chapter 1, Foreman et al. (1989b) found that physically disabled children were worse than matched classmates at drawing plan maps of their classroom, placing missing objects on an outline map and pointing in the direction of landmarks on their school campus. Simms (1987) found that disabled children, compared with able bodied matched controls, took significantly longer to learn a route, their observation of landmarks was poorer, they were less competent at marking routes on a sketch map and produced less comprehensive hand drawn sketch maps.

Simms (1987) also found a difference in spatial skill related to level of mobility. She found that walkers performed better than those who were wheelchair bound. The following study was designed to investigate degree of mobility as a factor in cognitive map formation. If exploratory experience is taken to be integral in forming an effective internal representation, it would be expected that level of spatial ability would be directly related to the level of mobility.
The design used in Experiment 3 was replicated to investigate the shortcut taking ability of physically disabled children. The participants were divided into two groups: one group were more mobile at an early age and their mobility had therefore deteriorated over time, and the second group were those children whose mobility had remained stable or improved with age. It was hypothesised that those children whose mobility was better when they were younger may have gained crucial exploratory experience at an early age and that they would be better able to form cognitive maps than those who had always experienced poor mobility. Participants were selected on the basis that they should be young enough to be likely to benefit from spatial learning tasks, but old enough to be able to adapt to the computer based paradigm.

Method

Participants

These were 24 able bodied children and 34 children with physical disabilities. Thirty six disabled children originally took part but two were excluded due to communication difficulties. The 24 able bodied children, 10 male, 14 female, had a mean age of 13.6 (SD: 0.49). The physically disabled children, 19 male, 15 female, had a mean age of 14.1 (SD: 1.50). Their conditions were: sixteen children with cerebral palsy, six with muscular dystrophy, five with spina bifida, one with a disabling skin disease (EB), one with spinal atrophy, one with all four limbs missing, one with spinal muscular atrophy, one with incontinentia pigmenti, one with arthrophyposis and one with brittle bones. The disabled children were selected
according to their mobility status and all fell within the normal range of intelligence according to their teacher’s assessment. Children were placed into one of two categories; either more mobile when they were younger (11 participants) or less mobile when they were younger (23 participants). School staff were asked for detailed information concerning the childrens’ conditions, and information about their mobility from childhood, and they were asked to rate each child as more or less mobile at present than when they were younger. (In two cases a child who walked early in life, but now used an electric wheelchair, was rated more mobile now, as a wheelchair had actually allowed the child to move around with more ease).

Design

The experimental design was the same as that of the first three experiments with both groups exploring three outer pathways. There was no control group who just explored two pathways as in Experiment 4 since the inclusion of such a group would have added nothing to the comparison of disabled and able-bodied group performance. This study employed a quasi-experimental research design in which the mobility status and history of the child, either less mobile (LM) or more mobile (MM) were studied using the measure of choice of route, scored as correct or incorrect.

Apparatus

The environment was the same as that used in Experiments 3 and 4, incorporating the four large cues.
Figure 5

The percentage of able bodied and disabled children who chose the shortcut during the test trials

- □ Able bodied
- ■ More mobile when younger (MM)
- ◼ Stable/improved mobility (LM)
Procedure

As in Experiment 3.

Results

Figure 5 illustrates the percentage of those in the three groups: able bodied, LM and MM who chose the correct route (the shortcut) during the two test trials. For shortcut 1, 58% of the able bodied group chose the correct path and 71% chose the correct path on shortcut 2. Chi-squared tests were calculated to compare the proportion of correct and incorrect responses for the able-bodied against the chance frequencies. The chi-squared values were significant for both the first ($\chi^2(1) = 6.75, p < 0.05$) and second shortcut tests ($\chi^2(1) = 4.17, p < 0.05$).

The disabled children were divided into 2 groups, those previously more mobile (MM) and those who were less mobile (LM) when they were younger. For shortcut 1, 45% of the MM group chose the shortcut, with 82% choosing the shortcut on the second trial. Chi-squared tests were calculated to compare the proportion of correct and incorrect responses for the MM group against the chance frequencies. The chi-squared values were non significant for the first test ($\chi^2(1) = 0.73, p > 0.05$) but significant on the second shortcut test ($\chi^2(1) = 4.45, p < 0.05$).

For shortcut 1, 39% of the LM group chose the correct path with only 43% choosing the correct path on shortcut 2. Chi-squared tests were calculated to compare the
proportion of correct and incorrect responses for the LM group against the chance
frequencies. The chi-squared values were non significant for both the first ($\chi^2 (1) = 0.35$, $p > 0.05$) and second shortcut tests ($\chi^2 (1) = 0.39$, $p > 0.05$).

A 2x3 contingency table revealed a significant deviation from the frequencies
expected by chance for trial 2. (Shortcut 1 Cramer’s $V [1] = 0.18$, $p > 0.05$; Shortcut 2
Cramer’s $V[1] = 0.32$, $p < 0.05$). The chi-square test showed significant differences
between the two disabled groups $\chi^2 (1) = 4.44$, $p < 0.05$, and between the able bodied
and the disabled group who were not more mobile (LM) when they were young $\chi^2 (1) = 3.60$, $p < 0.05$, but not between the able bodied and those disabled children who
were more mobile (MM) when they were young $\chi^2 (1) = 0.48$, $p > 0.05$. Results tables
can be found in Appendix I.

Discussion

The essential features of the results of Experiment 3 were replicated, in that able
bodied children were able to complete both shortcut tasks with better than chance
accuracy. Those disabled children who had poor mobility when young were unable to
select appropriate shortcuts. However, those who had experienced a period of good or
normal mobility at a younger age (and who had thus experienced autonomous
exploration within real environments) were able to complete the the second task with
better than chance accuracy. These data seem to confirm the important role of early
exploratory experience (see Acredolo, 1988) in establishing the general ability to
create and use internal representations of space. This study shows that this extends to virtual spatial representations.

Disabled children who had not been very mobile when young did not perform as well as able bodied children on the shortcut task, this raises the possibility that in order to benefit from simulation training they may need extra tuition. An interesting casual observation from this study was that most disabled children in the LM group appeared not to scan the environment. Despite being encouraged ‘to feel free to stop and look around you,’ they rarely did. In comparison, the majority of the able bodied children and some of the MM group stopped on the pathway and would turn through 360 degrees to scan the environment, presumably to help them link the position of the cues to the relevant rooms. Perhaps some disabled children need to be taught to perform these behaviours. Gaunet and Thinus-Blanc (1996), in a study looking at the exploration of blind participants, observed two different forms of exploration: cyclical or back and forth patterns. They suggested that organising strategies were involved in exploration and that the type of strategy used may be linked to the accuracy of the resulting internal representation. If optimal strategies could be trained, perhaps spatial navigational ability would be improved. Many of the children who were less mobile when young were actually gaining increased mobility, due to their gaining access to better wheelchairs. However, they seem to have developed a poor sense of spatial relationships, these children may benefit immensely from specific spatial navigational training.
Simms (1987), in her study, suggested that the disabled children, in comparison with their able bodied peers, may have had less experience with maps and giving directions, and therefore may have found these tasks unfamiliar. She suggests structured training at a young age to allow those with disabilities to become more efficient at finding their way around their neighbourhood. Simulation experience could provide this form of wayfinding experience. It maybe that children need to be prompted into thinking in a spatial way, to be made conscious of landmarks and to develop an awareness of their surroundings. VR training might enable a child to develop these spatial concepts.

If this study were replicated it may benefit from stricter categorisation into the more mobile/less mobile groups. A mobility scale was originally created for assessment means in the present study. However this scale was abandoned as there was a problem of parity, with different teachers rating children from their schools and thus the ratings between schools could not be compared. In the present study the experimenter relied on a teacher or nurse’s assessment of a child’s mobility status. Although all the assessors were familiar with the development of the children that they were categorising, future studies could incorporate a questionnaire to the child’s parents.

3.7 Summary

In their report of a shortcut task with hamsters, Chapuis et al (1987) stated that their apparatus “was housed in a room relatively rich in environmental cues such as windows, file cabinets, and doors” (p.175). In order for humans to be able to complete
a comparable task, in a virtual environment, the present studies (experiments 1-3) found that the type of external cue available in the environment was of great importance in determining participants’ performance.

The cues were arranged so that none was positioned directly behind a target room. Therefore, participants must have used the configuration of cues to represent the position of each room. Experiment 1 demonstrated that four small cues were inadequate for the creation of an internal spatial map. It was hypothesised that performance would improve if more than one cue were visible in each frame. Experiment 2 used continuous cues, but found a significant number of participants failed to use all of these, and consequently failed to complete both shortcuts. Experiment 3 increased the salience of just four cues so that there were always two cues visible on the screen, this was effective insofar as participants were able to complete both shortcuts with above chance accuracy. Experiment 4 showed that the paradigm was an effective assay of spatial mapping. It provided a successful replication of the original testing paradigm, since a linking element was shown to be necessary for the development of shortcut adoption. Experiment 5 compared the shortcut ability of able bodied children with that of physically disabled children having varying degrees of mobility impairment. It was found that those children who had had limited mobility from birth were poorer at the task than those who were mobile when young but whose mobility had deteriorated with age. The latter results add further weight to the argument that early independent exploration is essential for the development of cognitive spatial mapping ability in children.
Chapter 4

Successful Transfer of Spatial Knowledge from a Virtual to a Real School Environment

4.1 Introduction

The results of the previous experiment indicated the importance of early exploratory experience in the development of effective internal spatial representations. Virtual environments are suggested as a means with which to provide children with repeated, autonomous exploration which may help in the development of the type of spatial skills needed for successful navigation. However if VR is to be used in the training of spatial skills, it is essential that these skills transfer to the real world, such that for example, the individual can undertake practical spatial tasks more effectively. To date there are few experiments that address this issue. Regian et al (1992) taught able-bodied participants to navigate through a virtual office building. Those trained in the virtual building learned nearly as well as those who explored the real building and better than controls who were shown a series of photographs of the building. Witmer et al (1995), in a similar study, trained people to take routes through an office building, finding that building-trained students made fewer wrong turns than those trained in the virtual environment, who made fewer wrong turns than those trained verbally. Thus, virtual experience may not be quite as effective as real exploration, but it does impart spatial information of a quality which is potentially of practical use in
everyday situations. However, spatial skills have frequently been tested within the virtual world but not in a real equivalent (Regian et al, 1992).

With able-bodied adults, Wilson et al (in press (a)) have established that spatial knowledge (of vertical and horizontal positions of targets) in a real two-storey building can be acquired purely via exploration of an accurate virtual simulation. In a first study they tested 18 year-olds in a simulation of a building which none of the subjects had previously visited. Half of the participants explored the accurate (to-scale) simulation, while the other half explored the real building. All participants then completed spatial tests which included pointing to target objects encountered during exploration but not visible from the test site, estimating distances, and completing maps. All participants were found to be able to draw accurate maps and point to objects with considerably greater accuracy than a control group who made informed guesses without prior exposure to either the real or virtual environment.

It is also crucial to determine whether such findings apply to disabled users. Autonomous self-directed activity in VR has been shown to be beneficial in the training of learning disabled students to shop efficiently in supermarkets (Cromby et al, 1996). Two groups of students with severe learning difficulties were taken on two shopping trips separated by an eleven week interval. During this interval the experimental group were trained using the supermarket simulation, while the control group had equivalent exploratory experience but of alternative virtual environments. On the second trip to the real supermarket the experimental group proved to be faster
at completing a shopping task, picked up fewer goods while assembling the required shopping items, and chose more correct items than the control group.

In the only study to date which has examined transfer of VR to real life training in physically disabled children, Wilson et al (1996) asked children to explore a simulated building in the form of a game. They were required to activate each of several pieces of fire equipment in the course of exploration, and to open a fire door in order to “exit” the building. The children were then asked to indicate where they thought items of fire equipment were located in the real building using a pointing device situated in a room from which the target items of equipment were not visible. They were also asked to describe routes within the building. On completion of these tasks they escorted the experimenter to the real fire equipment. The children were more accurate than a guessing control group on all the tasks, and had obviously gained a great deal of information during their exploration of the simulation.

Some skills transfer better than others. In Regian et al’s study, participants learned both spatial-procedural tasks and spatial navigational skills within the virtual environment. However, in another study, Kozak et al (1993) failed to show transfer from a virtual environment to a real environment of a pick and place task. Ruddle et al (1997) recreated Thorndyke and Hayes-Roth’s (1982) study, using a virtual version of the building used in that study. They found that the measures of those trained in the virtual environment and those of people who worked in the real building were similar for euclidean distance and direction estimates. However participants trained in the virtual environment had difficulty estimating real distances. The reasons for such
transfer failures are unclear, but they might relate to such things as the authenticity of the virtual environment, or distracting differences between real and virtual environments such as a lack of tactile and vestibular feedback. Or perhaps, as the authors state, the fact that absolute distance estimation is inherently difficult in a VE. They also suggest that an added factor adversely affecting the user’s performance could be the difference between real field of view and the VE display field of view.

It is therefore important to consider differences between real and virtual environments that could influence the transferability of spatial information. Unlike the simplified environment used in previous studies (Wilson et al, in press (a)), a real living or working environment is full of distracting information and contains small cues and moveable items that might confuse or distract a child who is attempting to relate what they have seen in a simulation to its real equivalent. The Wilson et al study used a very simple environment which is easy to navigate around and remember.

The present study was designed to replicate the essential transfer of spatial information from a virtual to a real environment in the Wilson et al (1996) study. It also aims to extend this study in two ways. First a better rendered and more complex environment was constructed, that incorporated all but the finest detail. Second, the experiment was designed to look at the effects of training on a spatial task in a virtual environment.

The main areas of Ash Field School, a single tier special school in Leicester, were incorporated into a simulation. Disabled children from a different school were allowed
to explore the simulation (without visiting the real school) and were trained to carry out a set of spatial tasks. Following this training they were taken to the real school and given the same spatial tests that had been trained in the virtual school, and also some equivalent but untrained tests for comparison. It is possible that participants could make intelligent guesses about the spatial layout of the environment in the absence of environment-specific experience so a control group, who never explored the simulation, also completed the spatial tests within the real school.
4.2 Experiment 6

Method

Participants

The participants in the experimental group were 7 physically disabled children, 6 boys and one girl from Westbrook School in Long Eaton. They had a mean age of 12.3 years (SD: 1.38). The control group consisted of 7 undergraduate students, 2 female and 5 male with a mean age of 25.6 years (SD: 8.18). Eight children began the study but one boy had to be excluded on the final testing day due to an unforeseen medical problem. The form teacher selected the children on the basis of their mobility problems, with the proviso that they were within the normal range of intellectual attainment. All had normal vision, some corrected by glasses. Their conditions were: four children with cerebral palsy, two with muscular dystrophy, and one with spinal muscular atrophy. The undergraduates were recruited at Leicester University. Recruitment was on a voluntary basis.

Design

An independent groups design was used. Participants were allocated to two groups, the children to the experimental group and the undergraduate students to the control group. The experimental group explored a computer-simulated environment for five sessions over a period of one week. Each session comprised exploration of a VE
Figure 6a
Plan view of the primary section of Ash Field school
(original scaled map)

Legend:
- **CHA**: Classroom With Homeplay Area
- **KS 2**: Keystage 2
- **RR**: Researcher’s Room
- **MWC**: Miss What’s Classroom
- **LY**: Library
- **GT**: Girls’ Toilet
- **BT**: Boys’ Toilet
- **MOC**: Miss Over’s Classroom
- **STORE ROOM**: Room
- **TARGET**: Target
- **PLAYGROUND**: Playground
- **DOLLS HOUSE**: Dolls House
- **YOU ARE HERE!**: Location indicator
- **V1**: Location
- **V2**: Location
- **V3**: Location
- **FENCE**: Fence
- **CENTRAL AREA**: Central Area

The diagram shows the layout of the Ash Field school, including classrooms, playgrounds, and other facilities, with specific areas labeled for easy identification.
followed by tests of their knowledge of the environment. The control group did not explore the computer-simulated environment or complete any spatial knowledge tasks before testing, but made reasoned guesses on the spatial tests within the real school. A guessing control group of older participants has been used in previous studies (e.g. Wilson et al, 1996) and represents a stringent control against which to compare the performance of disabled children. The study employed a quasi-experimental research design in which the subject variable of disability v non disability was studied using measures of map completion, angle estimations using a pointing device, and measures of route knowledge.

Materials

The primary section of Ash Field School in Leicester was created to-scale using the Superscape Virtual Reality Toolkit, and was presented on a Pentium 100 with SVGA graphics, displayed on a 17 inch monitor. The environment (see figure 6a) consisted of an entrance door with a corridor leading into a central area and nine rooms. The storeroom was located off the first corridor on the right. Four classrooms, a library area, a small office and the girls and boys toilets were located around the central area. Two of the main classrooms were named after the teachers who taught there (e.g. “Miss Over’s room”) the other two classrooms were called “Keystage II” and “the room with the homeplay area.” The small office was named after the researcher who worked in that room. All the rooms contained distinctive features. The store-room contained boxes, computers and an unusual shaped table, one classroom contained a television set, another a home-play area. The walls of the girls toilet were pink and the
walls of the boys toilets were coloured yellow. The environment was kept up to date; for example, the travel poster on the wall in Keystage II depicted the current ongoing project in the real school. The library area was made distinctive by its book shelves. The central area contained a piano, some wheelchairs, walkers and a television set. The small office contained two computers.

Movement through the environment was controlled via the arrow keys on the keyboard, or using a specially designed joystick adapted from an original wheelchair control. A hand-operated pointing device consisted of a tripod stand with a 360 degree protractor marked in 5 degree intervals, and an arm which rotated 360 degrees, attached to which was a red pointer. This was used to indicate the estimated direction of locations within the real school during testing. A further pointing device was programmed into the computer for use by the experimental group and was positioned in two different viewpoint areas. Participants could rotate the computer pointing device 360 degrees at each viewpoint and “point” to objects using the cross sights in the centre of the computer screen. Outline plans of the simulated environment without their distinctive features (i.e. the rooms only) were printed out on A4 sheets of paper upon which all participants were asked to mark the location of each room.

**Procedure**

Before testing, the simulated school was taken to the real Ash Field school and several staff and students were asked to point out any obvious omissions or inconsistencies. The simulation was then modified according to their responses.
Each child in the experimental group spent five sessions over a five day period in which they explored the computer simulated environment. These sessions took place in their own school. None of the children had ever visited Ash Field school. At the initial session each child was shown the environment by the experimenter, told the room names, and the distinctive features in each room were pointed out. It was explained that on a particular day they would be taken to the real school that was simulated on the computer, and would be asked to find their way around and given various tests. They were then asked to explore the environment until they felt familiar with it.

During each session the children were asked to name each of the rooms whilst exploring the environment. After the first two sessions they were shown how to use the hand-operated pointing device and were asked to point to different locations in their school (the entrance to the school or the swimming pool) which were not visible from their position. This was so that they would be familiar with the device when they encountered it during testing within the real school. During the final three sessions, when each child stated they felt they now knew the layout of the environment, the computer programmed pointing device was introduced. The child was placed in one of two locations depending on the counterbalancing procedure. One location (V1 on figure 6a) was in the corridor leading to the central area by the library where the participant faced the piano. The second location (V2 on fig. 6a) was outside a classroom on the right side of the central area where the participant faced the door of the classroom directly opposite. The child was then asked to point to three target
objects (which were not visible from their position) using the crosssights on the computer screen. The crosssights acted as a pointer. After the child had 'pointed,' if their estimations were not absolutely accurate, they were shown the correct direction by the experimenter. On days 4 and 5, after exploration of the simulation, the participant was asked to complete a route test. The experimenter positioned the child's viewpoint in a room and asked them to find a target room. For example, the participant was placed in Miss. Over's classroom and was required to move directly to the store room. The counterbalancing procedure determined which one of two routes the participant completed. Both the computer pointing task and the route test served as a training element. It was expected that children would be better able to complete these tasks in the real school as they had been taught the correct responses in the simulated version.

Both groups of participants were subsequently taken to the real Ash Field school. Two separate testing days were arranged, one for the experimental group and one for the control group. It was explained to the control group that they were going to visit a school for disabled children and would be asked to complete a range of spatial tasks.

Each participant was tested individually. Firstly they were taken to the primary school entrance of the real environment. (The same location at which they had started their virtual exploration sessions). They were then presented with an outline map of the real environment on which their present location (the entrance door) was marked. They were asked to point out each of the 9 rooms in turn. The name of each room, with a
corresponding number (1-9), was presented on a separate sheet of paper. Their choice was numbered on the map.

The exact two locations from which the children had completed computer pointing tasks in the simulation (V1 and V2 on figure 6a) were measured within the real school. These locations were marked with a cross of sticky tape on the floor. A third location was now included (see V3 figure 6a). This location was outside the small office where the participant faced the T.V, the piano and wheelchairs in the central area. Each participant was asked to estimate the direction of target objects from each of these locations using the hand operated pointing device. For the first pointing task the child was positioned in the identical location (eg. V1) from which they had pointed to objects within the virtual environment, and they were required to point to the same three target objects. The child was then taken to the second location (eg. V2) and was required to point to the same three target objects. Finally, the child was taken to the third location (V3) and was asked to point to three different target objects. Thus nine error scores were recorded per participant.

Finally, each participant completed two route tests. The child was taken to a room and was asked to move directly to a target room. The first route was the identical to the one trained within the simulation (for example, Miss. Over’s room to the store room). The second route taken was between two different rooms (for example, Keystage II and Mrs. What’s classroom). The counterbalancing procedure determined which one of the two routes was taken first.
The mean pointing error from the three testing positions

NB Test positions 1-3 refer to the locations from which the position of objects was estimated within the real school.
Results

The error scores for angle estimation using the hand-operated pointing device were calculated as the difference in degrees between actual object direction and the participant's estimated direction. A two-factor mixed analysis of variance (ANOVA) was carried out on the mean error scores obtained by the experimental and control groups. The analysis was mixed: the between-subject factor was the two groups (experimental and control); and the within-subject factor was testing from three different locations. The ANOVA revealed a significant difference between the groups, $F(1,12) = 67.54$, $p < 0.01$ with the experimental group being more accurate in pointing than the control group. The location effect and the group by location interaction were both non significant $F(2,24) = 2.26$, $p > 0.05$ and $F(2,24) = 2.18$, $p > 0.05$ respectively. Figure 6b illustrates the mean pointing error from the three testing locations.

Map test scores were calculated by adding up the number of rooms correctly marked on a map. The mean score for the experimental group was greater than that for the control group, 5.6 and 0.7 out of 9 respectively. A Mann-Whitney U test revealed the difference to be significant ($z = 3.17$, $p < 0.05$). A Mann-Whitney U test was used when many of the scores were zero and there was not a normal distribution.

Route test scores were calculated by awarding 1 point for each correct route chosen and 0 for an incorrect route. A point was only awarded if the participant had moved directly to the goal room making no detour. Half points were not awarded. The mean
The findings suggest that disabled children can acquire spatial information about the layout of a complex single storey school from a virtual equivalent environment, and that despite the inevitable discrepancies in the detail of the appearance between real and virtual environments, the information can be used to practical benefit by disabled children.

The experimental group performed significantly better on all three tests. The children not only completed the tasks trained in the virtual school, but they also completed spatial tests that had not been trained in the virtual environment equally well. They were able to point to objects not directly visible, and take the experimenter to places that they had visited whilst exploring, but never been formally tested on. In order to complete these tasks the children must have built up a reasonably accurate internal spatial representation of the school.

The experimental group were significantly more accurate at estimating the position of objects not visible from their viewpoint. Participants had been given training on one viewpoint during their sessions using the computer simulated environment. It was therefore expected that they would perform reasonably well in the pointing test from
that viewpoint in the real environment. They were expected to be less accurate on the pointing test from the second viewpoint as they must orientate themselves from a new position. The most difficult task was expected to be pointing from the third location, as there was a new viewpoint and new target objects to contend with. However, as the results indicate, the experimental group were significantly more accurate in pointing than the control group from all 3 viewpoints and their error scores from each viewpoint were relatively stable. This further supports the conclusion that the children had acquired flexible, effective internal representations of the environment from the virtual simulation, enabling them to orient themselves from a number of different positions within the real environment.

The children were also significantly more accurate on the route tests than the control group. A strict scoring procedure was used on this task. When analysing the experimental group’s results for this test, only those four children who went directly to where they were asked were awarded a score. However, the other three did complete the route test correctly but may have taken a wrong turning or gone to the wrong room first. The corridor contained coat racks that were not seen in the simulation, this misled a couple of the children, as they saw the coat racks and concluded that the corridor was not the same one encountered in the simulation, when in fact it was. They realised their mistake and went on to find the correct room. However they were not awarded a point under these circumstances.

Ideally a matched control group should have been used in this study, but due to a limited pool of participants this was not possible. A control group of matched able-
bodied children may have provided an alternative control group as children are likely to be familiar with the spatial layout of schools, which contain similarities in design. Wilson et al (1996) used an adult control group in their study and suggest that adults represent a stringent control group because they can make intelligent guesses about spatial layouts in the absence of environment-specific experience, by analogy with what they have experienced before. As this experiment was a partial replication of Wilson et al’s (1996) study, a similar control group was used in this study. It is worth noting that had no differences been found between the measures of the disabled group and the control group, a real difference may have been masked by the fact that the adults were extremely good at guessing. Fortunately, this was not the case in the present study and is therefore not an issue.

The disabled childrens’ performance on this study was particularly encouraging considering the following factors regarding the testing situation. The simulation lacked fine detail. Labels on the doors of many rooms were purposely omitted from the simulation. If this environment was constructed for training purposes obviously these labels would be included and would make the user’s task easier. Some participants were necessarily tested during break times between lessons, with the consequent added distraction of noise and other children, neither of which were encountered when exploring the simulation.

The real environment was much more cluttered with books, wheelchairs and school equipment than the simulation. A balance had to be struck between the amount of detail and speed in updating the environment. The more detail the computer has to
process, the slower the simulation runs. However, in the real world, it would not be sensible to navigate on the basis of small moveable items, and there is no reason for thinking that participants in virtual environments would use such cues either. Therefore, while fine detail was absent from the simulation, it is unlikely that this greatly affected participants’ spatial judgments. However what is clutter to one individual or at one time may be essential information to another user or at another time (Wickens and Baker, 1995). For example, the large television set in the school is moveable and thus may not seem important to include, however as it is always kept in the main central area in a particular position it is actually a fairly prominent landmark! This simulated environment was successful in that it seemed to contain adequate detail for the children to be able to gain spatial information that transfers to the real school. However research into the level of detail needed to gain the optimum benefit from the environment is needed. Although realism is important, too much detail may cause distractions and detract from the main aim of the task.

In conclusion, this study demonstrates the potential value of 3-D simulations in training spatial skills, that transfer to real environments, supporting and extending the findings of Wilson, Foreman & Tlauka (1996). In these studies, the only two studies examining transfer of spatial information from simulations to real environments by physically disabled children, a high degree of transfer was found. This suggests the potential use of VE’s in enabling disabled children to gain spatial information about real places before visiting them. The following experiments look at the effect of repeated exploration of virtual environments and examines the outcome of this exposure on spatial representational ability.
Chapter 5

Enhancing the Spatial Skills of Physically Disabled Children using Virtual Reality

5.1 Introduction

The results of experiment 5 suggested that limited independent exploration leaves disabled children with poor spatial knowledge. They have problems forming effective internal spatial representations of their environments. This poor spatial knowledge may have educational implications, but it also creates a feeling of disempowerment, adversely affecting the individual’s confidence in public places (Foreman, Wilson and Stanton, 1995). Therefore it would be of great benefit to provide these children with added exploratory experience in order to improve their spatial navigational skills. Virtual environments have been suggested as a medium via which these skills might be conveyed.

However, if skills are learned in a virtual environment it is essential that they transfer to the real environment, for the experience gained in a VE to be of any real benefit. The previous study investigated the transfer of spatial knowledge from a virtual to a real environment, establishing that physically disabled children can acquire substantial spatial knowledge from virtual exploration alone. Simulations have been used successfully to train wayfinding abilities (Hunt et al., 1987; Ruddle et al., 1997). The following studies examined whether physically disabled children’s spatial skills
improve with VE training. Repeated exploration of real environments leads to increasingly effective internal representations of subsequent real environments (see Chapter 1). The present chapter examines whether repeated exploration of several virtual environments promotes better encoding of virtual environments in general. If this is found to be so, children and adults could benefit from virtual exploration, as a supplement to real world exploration. Virtual reality training may be beneficial in teaching children to think ‘spatially’ about environments and become more aware of their immediate surroundings.

The following three studies examined whether computer simulated environments could be used to train spatial skills generally, i.e., whether spatial-perceptual abilities per se are enhanced with repeated virtual testing. The first experiment examined whether skills acquired by children using a simulated environment are specific to that environment, or whether they transfer to subsequently experienced environments.
5.2 Experiment 7

Method

Participants

These were 8 physically disabled children, 4 boys and 4 girls. They had a mean age of 11.88 years (SD: 2.62). Children selected for the study were those having substantial mobility problems. Their conditions were: one child with cerebral palsy, one with brittle bones, two with paraplegia, one with spina bifida, one with an inoperable heart condition, one suffering from severe breathing problems, and one with hemiplegia. Every child was able to use a computer keyboard.

Design.

All participants explored three computer-simulated environments at fortnightly intervals. Each session consisted of an exploration phase followed by a number of tests of spatial knowledge. A different environment was explored in each session but the spatial tests remained the same. The independent variables were the layout of the environments and the positions of six target objects. The dependent variables were the participants’ angle estimations (made using two different types of pointing device), the time taken to find a specified object, and the quality of maps that participants were able to draw of the experimental environment.
Figure 7a

Plan view of the first novel test environment
Figure 7b

Plan view of the second novel test environment
Figure 7c
Plan view of the third novel test environment
Apparatus

The virtual environments were created using Superscape Virtual Reality Toolkit and were presented on an Intel Pentium 90 with SVGA graphics, displayed on a 14 inch monitor. All three environments consisted of three rooms joined by a T-shaped corridor (see Figures 7a). Each room was subdivided into smaller sections using two or three walls of ceiling height. In the first environment each room was coloured differently: one burgundy, one pale green and one blue, such that they were clearly discriminable. In the corridor leading out of the central (pale green) room was a START sign. Movements of the viewpoint were controlled using keyboard arrow keys. The viewpoint was 18000 units in height and the walls were 45000 units high. Six objects were placed in the environment, two in each room. These objects were: a piano, an animated shape, a flag, a decorated shield, a camera, and a rotating globe. In order to measure the participants’ estimates of the positions of objects in the environment, three testing viewpoints were programmed, one in each room (marked with x’s on Figure 7a). At each viewpoint participants could pan 360 degrees around the Y-axis, direction being recorded in 5 degree steps. These viewpoints were used to record accuracy of pointing using the screen cross-sights. The second pointing device was a hand held pointing device. This was made from a flat, circular piece of board coloured blue and red. A full circle was marked on the board, segmented in 5 degree steps and a moveable arrow, rotating about the centre of the circle, was used by participants to indicate chosen directions/angles. When using the hand pointing device the same three testing positions were presented on the screen as were used for the computer pointing estimates. A schematic plan view of the environment (minus the
objects) was generated on A4 paper for an object placement task, in which participants had to place small crosses to indicate where they thought the objects were located.

The second virtual test environment was coloured differently. One room was pink, one turquoise and one orange, and the starting point was moved from the centre room to the right hand (orange) room. Six objects were placed in the environment, two in each room, in the same positions as those occupied by objects in the previous experiment. These objects were: a tank, a postbox, a traffic cone, a “no smoking” sign, a torch and an animated robot (see Figure 7b). In the third environment, the rooms were rearranged so that the room that was originally on the right hand side of the corridor was now on the left, the original left hand room being moved to the centre position and the original central room being to the right hand side. Each room was again coloured differently, one yellow, one dark green and one stone. The starting point was placed in the left hand (green) room. Six objects were placed in the environment, two in each room. These objects were: a rotating fairground wheel, a star, a map of the U.K., a car, a clock and an animated insect. Three testing viewpoints were again programmed; however they were positioned differently from those in the previous two environments (see Figure 7c). A stopwatch was used to measure the time taken to find a chosen object before and after exploration.
Procedure

Participants were tested individually. At the beginning of each session the experimenter demonstrated a tour through the environment, beginning at the starting point and visiting each room in turn before returning to the starting point. Participants were told to explore the environment, find the six objects, and try to remember both where the objects were located and the layout of the environment. They were made aware that their memory would later be tested. The participant was then given a demonstration of the type of pointing task that they would be asked to complete following exploration.

Before commencing general exploration, the participant was first asked to locate one object, picked randomly by the experimenter, as fast as possible. Latency to find the object was recorded and the experimenter then reset the viewpoint to the starting point. (On test days 2 and 3, the selected test object was always located in a different position from the one used in the previous session, and was always an object that occupied a location distant from the starting point rather than an adjacent location). The participant was then asked to explore the environment for as long as necessary for them to feel confident about being able to carry out the tests. The experimenter monitored the participant’s exploration to ensure that all six objects had been encountered. When the participant indicated that they felt confident about their familiarity with the environmental layout, the experimenter used the keyboard keys to “transport” them from the starting point to each of the testing points in turn, where they were asked to point toward all six objects in turn, either using the cross sights in
the centre of the computer screen (half of the participants) or the hand held pointer (the remaining half). The three testing points were then retested in the same order. The participant was then given the same test but using the alternative pointing device (screen-based, or hand-held). Each participant used the pointing devices in the same order for all three test environments. Note that since participants were “led” from the starting point by the experimenter to each of the testing positions they could monitor their route through the environment. This should have prevented any disorientation caused by being instantly transferred to one particular location in this relatively bland environment. None of the objects was visible from any of the testing positions.

In the second environment the testing positions were in the same place as in the first, but they were visited in a different order. When the pointing task was completed the experimenter returned the participant back to the starting point and asked them to find once again, as quickly as possible, the object that they had been asked to locate before exploration. The experimenter recorded the time taken. Next, the participant was given a blank sheet of A4 paper and asked to draw an outline of the test environment and indicate the positions of all of the 6 objects. Finally, a plan outline of the environment was presented to the participant who was asked to mark the positions of all objects as accurately as possible.
Figure 7d

Group error scores for angle estimations using the computer pointing device.
Figure 7e

Time taken to find a given object.

- Test 1: Before exploration
- Test 3: After exploration
Figure 7f

Mean error scores for objects positioned on an outline map

![Bar chart showing mean error (degrees) for Test 1 and Test 3. The mean error for Test 1 is significantly higher than for Test 3.](image)
Results

A repeated measures analysis of variance (ANOVA) was carried out on median angle estimation error scores using the computer pointing device. A significant main effect was found, $F(2,14) = 6.56$, $p < 0.05$, reflecting significant differences among sessions. A Newman Keuls test showed that session 3 error scores were lower than those of session 1 and 2, but that scores for sessions 1 and 2 did not differ (see Figure 7d). For equivalent scores using the hand-held device, no significant effects were obtained, $F(2,12) = 0.83$, $p > 0.05$.

The time taken to find a given object before and after exploration is shown in figure 7e. One tailed $t$-tests were used to assess the significance of differences. There was a significant drop in the latency before exploration $t (7) = 2.64$, $p < 0.05$ and also after exploration $t (7) = 1.98$, $p < 0.05$. Error scores for the object placement mapping task were computed as the difference in degrees between the actual object direction and the childrens’ indicated direction. These were averaged across objects for each map. A paired samples $t$-test was conducted on the mean error scores for objects positioned on an outline map. The mean error scores for tests 1 and 3 were 55.7 (SD = 32.8) and 30.3 (SD = 21.0), respectively; a difference that was found to be significant, $t (7) = 3.02$, $p < 0.05$. (Figure 7f). There was no significant effect for the hand drawn maps, $t (6) = 1.63$, $p > 0.05$. Results tables can be found in Appendix I.
Discussion

The results show that on several criteria, childrens' performance on spatial tasks improves with repeated experience of virtual environments. Improvement was evident when measured using the crossights in the centre of the computer screen as a pointing device, but no improvement was seen when the hand pointing device was used. The latter device requires a fairly complex transformation from large-scale simulated locomotor space to a small, real-world artificial device, which proved difficult for the children to use. From their verbal reports, they appeared to have problems relating the direction of the pointer to simulated locations. The ANOVA on the median error scores for angle estimations using computer pointing shows that error scores reduced significantly over trials, though post hoc analysis revealed that improvement was evident only by test 3 (which differed significantly from both tests 1 and 2). Little improvement occurred between the first 2 test sessions. Childrens’ positioning of objects on an outline map improved significantly between test 1 and 3, though their hand drawn maps did not show any significant change. The latter measure is subject to great variability and is often deemed a less powerful measure of cognitive map formation (Evans et al., 1980; Evans and Pezdec, 1980; Herman and Siegel, 1978; Levine et al., 1982). The average time the children required to find a selected object was greatly reduced after exploration, indicating that they had learned specific routes. However there was a general practice effect involved, inasmuch as children were faster both before and after exploration on the last session when compared with the first.
A possible confounding factor in the experimental design was that the order in which participants explored the environments was not counterbalanced. Although there may be differences between environments in terms of their navigability, this is unlikely to have influenced the results since each environment in the present study was constructed from the same basic elements (i.e., the same three rooms and the same corridor.)

The results of this study are very encouraging since diminishing error scores are likely to reflect children's improved use of some form of internal representation which is necessary for the solution of the tasks. The fact that significant improvement only emerged in test 3 suggests that at least three exposures are needed for learning to take place.
5.3 Experiment 8

Introduction

Having shown that children's spatial abilities improved after exploring virtual environments, it was necessary to establish that this improvement was due to the interactivity and three-dimensionality of the virtual environments and not to other non-specific factors such as improved confidence and familiarity with the experimenter, or computer and keyboard familiarity. This was examined in Experiment 8 by comparing 3-D exploration with 2-D (control) exploration. Navigational measures were supplemented by other spatial tasks, measuring various aspects of visuo-spatial skill, including spatial visualization. Spatial visualization has been defined as the "ability to mentally manipulate, rotate, twist or invert pictorially presented visual stimulus" (McGee, 1982, p.4). There were reasons for thinking that improvement in spatial skill after exposure to VE's might generalise to other tasks that may draw on a 'spatial' brain module (Neisser, 1976). These additional tests were therefore carried out to test the generality of cognitive spatial improvement occurring after 3-D training.
Method

Participants

There were 24 physically disabled children, 3 girls and 21 boys. They had a mean age of 10.38 years (SD: 1.97). The participants were again selected as those having substantial mobility problems. Their conditions were: sixteen children with cerebral palsy, four with muscular dystrophy, two with spina bifida, one with spinal muscular atrophy and one with girdle dystrophy. The sex ratio is uneven as at the time of recruitment there were few girls fitting the criteria in the participating schools.

Design

A pretest consisting of a battery of three spatial tasks (see below) was followed by four 30 min. sessions of interaction with either two dimensional or three dimensional computer graphics in a “game” format. Participants were then retested on the same battery of spatial tasks as in Experiment 7. Note that this design ensured that children in both experimental and control conditions spent an equal amount of time with the experimenter and gained an equal degree of familiarity with the keyboard.

Apparatus

The virtual environments used in Experiment 7 were reused in one of the spatial tests in this study, though here they were presented in counterbalanced order to avoid
effects due to differential navigability. In addition the *Money Standardized Road-Map Test of Directional Sense* was used and an adapted version of the *Shepard and Metzler Mental Rotation Test*. The Money Road-Map Test requires participants to follow a route through a stylised street map, and make judgments at 32 turning points as to whether a turn is to the right or to the left. (The difficulty in the task is that participants have to make these judgments when “travelling” in different directions on the page.) They are not allowed to rotate the paper. The adapted Shepard and Metzler Test consists of thirty two pictures of a geometric shape which is composed of seven cubes. The shapes were created using Superscape Virtual Reality Toolkit and were printed in black and white. One shape was created and eight of the 32 pictures displayed this shape in different orientations, rotated in the (depth) z-plane by various angles about its centre point. Another eight pictures showed the shape rotated through various angles in the (picture) y-plane about its centre point. The original shape was then reflected 180 degrees and eight of the pictures displayed this shape at various degrees of (depth) z-plane rotation, and the final eight pictures displayed this shape at various degrees of (picture) y-plane rotation. (For examples see Appendix II).

**Procedure**

Each child attended six test sessions. In the first session the child was given the Money Road-Map and the modified Shepard and Metzler Mental Rotation tests. Before taking the Money test, participants were asked to indicate first their right hand and then their left ear. (All participants could do this easily.) The map was then placed before the participant, who was told to imagine that they were following the path
shown on the map and at each turn to say whether they would be making a left or a right turn. Participants then followed a short practice route, the experimenter correcting any mistakes that they made. The full test then followed, during which no feedback or assistance was given and there was no time limit.

For the Shepard and Metzler test, each participant was shown examples of the original shape rotating on the computer screen and was then tested on the thirty two pictures. They were provided with a reference picture of the original shape, and they were shown the thirty two pictures one at a time. The participant had to say, for each picture, whether it was the same shape as the reference or a different shape, the different shape being the reflected shape. Participants were shown eight depth pictures (four the same, four different), eight picture plane pictures (four the same, four different), and sixteen of the depth and picture plane shuffled (eight the same, eight different). The pictures were shuffled between participants.

At this point the child explored one of the novel environments used in Experiment 7 and completed the same spatial tests (finding an object as quickly as possible, estimating angles from given positions and drawing maps). Half of the children were assigned to the 2-D and half to the 3-D groups. The next four sessions consisted of individual 30 min. sessions of exposure to either two dimensional, or three dimensional environments which the child explored with the experimenter. The two dimensional environments were selected from the popular games market and consisted of non-violent platform and adventure games. The three dimensional environments were created using Superscape Virtual Reality Toolkit and consisted of large scale and
Figure 8a

Two dimensional vs three dimensional interaction for angle estimations using the computer pointing device.
small scale environments (such as a leisure centre or an office) in which the child could explore and interact with objects. The exploration was presented in the form of a game by asking the child to try and find objects and interact with them. Both the 2-D and the 3-D environments required similar keyboard 'activity.'

Finally, in the sixth session the children carried out the same tests as in the first session (the Money test, the Shepard and Metzler Test, exploration of a novel virtual environment) and were tested in the same way as previously. Note that the novel environment was different from the one explored in the first session.

**Results.**

Two participants were unable to draw a map due to poor hand movement and two different participants were unable to complete the Shepard and Metzler task due to lack of concentration. The analysis of these two measures is thus based on twenty two participants rather than the original twenty four.

A two factor mixed ANOVA was carried out on the median error scores for computer pointing for 2-D and 3-D groups. An interaction was found between the 2-D/3-D factor and test sessions, \( F(1, 22) = 6.34, p < 0.05 \). Simple main effects analysis on the interaction revealed that the groups did not differ significantly at the pretest, \( F<1, \) and the difference fell just short of significance at the posttest, \( F(1,22) = 4.071, p > 0.05 \). This analysis also revealed that the 3-D group significantly decreased their error scores from pre- to posttest, \( F(1,11) = 5.177, p < 0.05 \), but the same was not true for
Figure 8b

Time taken to find a given object for the 3D group.

- Before exploration
- After exploration
Figure 8c

Time taken to find a given object for the 2D group.
the 2-D group, $F(1,11) = 1.688, p > 0.05$ (see Figure 8a). The time taken before and after exploration at pretest and posttest in both conditions are illustrated in figures 8b and 8c. Although the scores for the 3-D group, after exploration, were falling in the right direction, they failed to reach significance when analysed using a two factor mixed ANOVA, $F(1,22) = 2.41, p > 0.05$. A two factor mixed ANOVA carried out on the error scores for objects placed on the outline map ($F[1,22] = 0.25, p > 0.05$), and on the hand drawn map ($F[1,20] = 0.42, p > 0.05$) revealed no significant differences from pretest to posttest or by condition. Test scores (the number of correct responses) from both the Money Road and the Shepard and Metzler tests, analysed using a two factor mixed ANOVA, failed to reveal improvement from pretest to posttest ($F[1,22] = 0.17, p > 0.05$ and $F[1,20] = 1.83, p > 0.05$ respectively). Results tables can be found in Appendix I.

**Discussion.**

The results show that childrens’ scores on navigational spatial tasks improve when they use 3-D training but not 2-D training. This was particularly clear from the task which has been found in this and other studies to be the most effective measure of spatial skill, namely the computer pointing task. The data support the notion that improvement in spatial skill seen in this and previous experiments is specifically due to the unique features of simulated environments created using 3-D graphics, namely three dimensionality and real-time interactivity. The interaction reveals a difference between the performance of the 2-D and 3-D groups between pretest and posttest. While the rise in 2-D scores (i.e., a slight worsening in performance) between pretest
to posttest was surprising, the significant drop in the scores of 3-D participants (i.e., significantly improved scores) reflects their improved spatial performance. The reduced time taken to find a given object by 3-D participants further reinforces this conclusion, suggesting that children in this group had learned routes and acquired navigational information of a kind that would be beneficial in an equivalent real environment. For the 2-D condition the posttest time score (after exploration) was actually higher than the corresponding pretest score. This could not be due to differences in the navigability of the pretest and posttest environments, as the order in which they were used was counterbalanced.

Measures of competence in drawing maps and placing objects on outline maps failed to reveal any improvements in the posttest phase, though these measures are subject to considerable variability, largely due to difficulties in choosing appropriate scoring criteria (Evans et al., 1980). The present study used the most objective measure of scoring by calculating angular error scores. The Money Road-Map and the Shepard and Metzler tests also failed to reveal improvement, after 2-D or 3-D experience, and thus it is reasonable to conclude that spatial skills learned in a virtual environment are fairly specific. There is apparently no generalisation to non-navigational skills, which may reflect a quite different set of underlying visuo-spatial cognitive abilities. Further study is needed in this area, however the present results argue against the existence of a universal ‘spatial’ brain module (Neisser, 1976).

The aim of this study was to establish that improvement in spatial skill was due to the interactivity and three-dimensionality of the virtual environments and not to other
non-specific factors such as improved confidence and familiarity with the experimenter, or computer and keyboard familiarity. It would be interesting to compare 2-D maps with their 3-D counterparts but this was not the issue here.

In the present experiment in which participants explored large and small scale environments, it was found that when the participant was in a small scale space (just one room) little exploration took place. The participant spent the majority of the time purely interacting with objects. The problems children are most likely to encounter in reality are more likely to occur in larger scale environments where all goals cannot be viewed from a single point in the environment. This issue is explored in the following study.
5.4 Experiment 9

Introduction

A follow-up to the previous study was conducted to examine the extent of improvement in spatial skill after training in virtual environments. In the previous study, participants explored large and small scale spaces. In the present experiment all the environments were large scale in order to encourage exploration and cognitive mapping skills to develop and to overcome the problems associated with small scale space encountered in Experiment 8. As the problems that children are most likely to encounter in real environments will often be in larger scale visually “dis-connected” spaces, where goals cannot be seen from one sub-space to another, it is important to use large scale simulations to examine this form of mapping.

It was hypothesised that with more intensive training, with the larger scale 3-D environments, spatial skills would show greater improvement. Children apparently lacked concentration when exploring two of the environments in the last experiment as they were small scale, and therefore they were able to scan the whole environment from one vantage point. In the present study all four environments were large scale and thus were expected to encourage exploration.
Participants

There were eight physically disabled children, 5 were girls and 3 were boys. They had a mean age of 14.3 years (SD: 1.16). The recruitment of younger participants proved difficult as there were few available children who had not taken part in a study. These participants are therefore slightly older. However they were of approximately the same age as those participants in chapter 5 who had difficulty completing the shortcut task successfully presumably due to problems in forming an efficient internal representation of the environment. The participants were selected on the same criteria as the last two experiments. Their conditions were: three children with cerebral palsy, two with spina bifida, one with a severe skin disease, one with spinal atrophy and one with muscular dystrophy.

Design

A pretest consisted of exploration of one of the novel environments described in the last two experiments, and then completing the same spatial tests (finding an object as quickly as possible, estimating angles from given positions and drawing maps). Each child then received four 30-50 min. periods of intensive exploration of complex, large scale three dimensional environments. The post test involved exploring a different novel environment from that in the pretest, but again completing the same spatial tests.
Apparatus

The novel virtual environments used in the last two experiments were used and presentation order was again counterbalanced.

Procedure

Each child attended six test sessions. In the first session the child explored one of the novel environments (consisting of three rooms connected by a T-shaped corridor) and completed the same spatial tasks (finding an object as quickly as possible, estimating the position of given objects and drawing maps) as in Experiment 8. Then each child attended four sessions over four days. These sessions varied from 30-50 mins. depending on the time taken for the participant to state that they were familiar with the environment. During these sessions children explored a variety of large scale environments (a school, a city, a leisure centre and a toy shop). It is important to note that the four environments used for training purposes were designed with very different layouts from that of the test environment. In particular, they were all based on places that were identifiably “real.” Exploration was again presented in the form of a game, where children must try and remember the position of objects in order to be able to locate them again. In the final session each participant explored a different novel environment and completed the same spatial tasks as were employed in the pretest.
Figure 9a

Group error scores for angle estimations using the computer pointing device.
Figure 9b

Time taken to find a given object.

The graph shows the time taken to find a given object during pretest and posttest, with bars indicating the time before and after exploration. The x-axis represents the test times, and the y-axis represents the time in seconds. The bars for pretest and posttest are labeled accordingly.
Results

The data were analysed using one tailed t-tests. The analysis revealed a significant difference between pretest and posttest error scores for the computer pointing task, \( t(7) = 1.96, p < 0.05 \) one-tailed, showing that children were again better able to point to objects that were not visible from the test viewpoint, following exploration of successive virtual environments (see Figure 9a). The time taken to find a given object before and after exploration is shown in figure 9b. There was a significant drop in the latency before exploration \( t(7) = 2.28, p < 0.05 \), but no significant difference after exploration \( t(7) = 1.50, p > 0.05 \), with the posttest after exploration score being higher than the equivalent pretest score. The results for the drawn and outline map tests showed no significant improvement, \( t(7) = 0.70, p > 0.05 \) and \( t(7) = 0.20, p > 0.05 \), respectively.

Discussion

The computer pointing task, again, demonstrated a significant improvement in performance from pretest to posttest. The results provide yet further evidence of improvement in spatial skills after exploration of three dimensional computer simulated environments. Although this measure was the only one to show significant improvement, it has proved to be an effective measure in all the current studies, and it is the only measure that can be carried out within the VE, avoiding any of the complications associated with external measures (such as maps, the problems of which were discussed in chapter 1 and mentioned in the last two studies).
Time taken to find a given object did not improve significantly from pretest to posttest. Three of the children took a wrong turn on the final route test, they continued on this route and did not realise their mistake until they reached a room. Their continuing on the wrong route could be partly due to the absence of visual cues in the rather bland testing environment. Measures of competence in drawing maps and placing objects on outline maps failed to reveal any improvements in the posttest phase.

Virtual environment exploration appears to encourage children to take notice of the spatial arrangement of environments. The improvement in spatial skill after repeatedly exploring virtual environments could have important implications. Prolonged exploratory experience may give children more confidence than brief exposures when they come to explore real environments. Chapter 4 demonstrated that the spatial skills learned in a virtual environment transfer to the real environment. The implication of the present experiment is that training could invoke a spiralling effect, whereby virtual exploration not only supplements real world exploration, but facilitates it. A child who has actively searched for cues in a VE may be more likely to acquire spatial information when moving around in reality.

5.5 Summary

It is evident from the experiments presented in this chapter that there is a transfer of spatial skill from one virtual environment to another and that this improvement in
spatial ability is primarily due to the interactivity and three dimensionality of virtual environments. These results have important implications for disabled children in that virtual reality is proving to be a potential training medium for skills that could enhance quality of life for many of them.
Chapter 6

Conclusions

This thesis has been concerned with the application of virtual reality to spatial cognition and disability. Previous research had shown that children with limited mobility have difficulty acquiring spatial skills due to limited independent exploration of their surroundings (Foreman et al., 1989). This has consequences for their intellectual development, and also leads to difficulty in wayfinding and lack of confidence in public places (Foreman et al., 1995). However, it was not known whether VR would be a suitable means of improving spatial skills: specifically whether accurate spatial information would be obtained from two-dimensional computer screens, whether this knowledge would transfer to real equivalent environments, whether disabled children could interact with virtual environments successfully, or whether they would gain long-term cognitive benefits from such training.

Chapter one outlined the concept of the cognitive spatial map and reviewed the research illustrating a strong link between extensive independent exploration of one’s surroundings and the subsequent formation of a highly flexible internal representation of that space. The formation of such “survey” representations in animals, children and adults was discussed, along with the problems in wayfinding and cognitive map formation experienced by children and adults with physical disabilities that limit their mobility and autonomous choice when moving around.
In Chapter one, the need for spatial encoding to overcome the dangers of living in a three-dimensional world were discussed (Glenberg, 1997). This thesis has outlined reasons why these dangers are more serious for those individuals with disabilities: due to factors such as poor mobility, limited independence, lack of autonomous choices when moving around and limited accessibility within public places. These are but a few of the problems many people with disabilities face every day. VR may in the future be used to supplement real life exploration; it is a revolutionary tool that enables autonomous activity and movement around simulated environments with little need for actual physical exertion.

The work carried out in this series of experiments has demonstrated that children with limited mobility have difficulty when faced with spatial tasks of a kind that require the use of an effective internal representation for their solution. Spatial information acquired in the course of exploring a simulated VE has been shown to transfer to an equivalent real environment, and a particularly large improvement in spatial navigational skill has been demonstrated following repeated exploration of virtual environments.

Chapter two illustrated the potential of virtual environments for the disabled user. The construction of VE’s was discussed along with the advantages and drawbacks of this technology. The aim of this thesis was therefore to explore the possible use of VE’s by disabled and able bodied children, and to assess the benefits of virtual exploration in developing the spatial navigational skills of the disabled children.
The five studies described in Chapter three assessed shortcut ability which is arguably dependent on the formation of a cognitive map. VE's were used in these studies as they gave the experimenter complete control over which cues the participant was exposed to within the environment (see Mohl, 1981). Experiments one, two and three examined shortcut ability in able-bodied children. These experiments were preliminary studies that attempted to find the optimal parameters for learning, and therefore control groups were not crucial. The results from these experiments indicated that four large cues, rather than small or continuous cues, were required in order to form the flexible internal representation needed to complete the shortcut task. This confirmed theories that some landmarks are more effective than others (Allen et al, 1978) and that in some situations landmarks need to be particularly salient to compete with egocentric responding (cf. Acredolo and Evans, 1980; Witmer et al, 1995).

Experiment four demonstrated that the chosen paradigm was an effective measure of spatial mapping, as a linking element between subspaces was shown to be necessary for the development of a complete internal map, in order that a shortcut could be chosen. For successful completion of this task oriented behaviour needed to be independent of a given pathway (see Chapuis and Varlet, 1987; Pick and Lockman, 1981; Poucet, 1985; Shepard, 1933).

Experiment five compared the shortcut ability of two groups of physically disabled children to that of a matched group of able-bodied children. Those disabled children who had experienced poor mobility throughout their lives, and/or whose limited
mobility had improved with age, were unable to take short-cuts to solve the task. However, those who had experienced a period of good or normal mobility at a younger age (and who had thus experienced autonomous exploration within real environments at an earlier time in their lives) were able successfully to complete the task. The results of this study further the hypothesis that early independent exploration is essential for the development of cognitive spatial mapping ability in children ((Billinghurst and Weghorst, 1995; Fraiberg, 1959; Gibson, 1979; Held and Hein, 1963; Mahler et al., 1975) and reinforce the results of other studies looking at the development of internal spatial representations in disabled children (Campos et al., 1982; Foreman et al., 1989; Simms, 1987). Although not examined directly in this thesis, it is possible that young disabled children might benefit particularly from the use of VE’s to train spatial skill.

Chapter four demonstrated a successful transfer of spatial information from a simulation to the equivalent real environment. Seven disabled children explored an accurately scaled simulation of a school that they had never visited before. They were then taken to the real school where they carried out three tests of spatial skill. The disabled group performed significantly better, on all three tasks, than a control group who did not have the benefit of exploring the simulation but made reasoned guesses on the tasks within the real school. This study demonstrated the potential value of 3-D simulations in imparting spatial information, that transfer to real environments. The results of this study support and extend the findings of Wilson, Foreman & Tlauka (1996).
Chapter five outlined three studies demonstrating that spatial skills can be trained and enhanced with repeated exploration of computer simulated environments. Experiment seven investigated transfer of spatial skills between different virtual environments. The results confirmed that the skills that disabled children gained using computer simulated environments improved with exposure to successive environments. To eliminate the possibility that learning was non-specific, Experiment eight compared 3-D exploration with 2-D (control) exploration, finding the former to be superior. Thus the interactivity and three-dimensionality of virtual environments seem to be crucial to spatial learning. Experiment nine examined the extent of improvement in spatial skills following intensive 3-D exploration and again illustrated a significant improvement in skills after training. These results confirm the importance of repeated exploration in building up more accurate internal spatial representations of one’s surroundings (Allen et al., 1978; Herman and Siegel, 1978; Kozlowski and Bryant, 1977). A combination of tasks was used to assess spatial knowledge in order to gain a more complete view of the type of information that children were acquiring. The computer pointing task was found to be the most effective test. This is not surprising as this measure enables testing of spatial knowledge via the same medium in which exploration, and thus the acquisition of spatial knowledge took place, and eliminates many of the problems associated with assessing childrens’ internal representations (see Herman and Siegel, 1978). However maps were also used. Billinghurst and Weghorst (1995) claim that when users’ are orientated within a VE they produce better sketch maps. The present studies found that the hand drawn maps, due to their huge variability, proved difficult to analyse (see Evans et al., 1980) and did not appear
to represent the spatial knowledge that had evidently be acquired and which was externalised via the pointing tasks (cf. Evans and Pezdek, 1980; Levine et al, 1982).

A great deal of time and effort was required to recruit the participants for the present research project, and they were necessarily selected from a limited pool. Greater participant numbers and greater uniformity in their range of mobility impairing conditions would have been ideal in order to draw more specific conclusions. However, that improvements in spatial learning, and transfer of spatial knowledge to real equivalents, occurred with such small samples, and in such a diverse population of individuals, suggests that the benefits of learning from simulations is robust.

There are many directions for future research. There is a need to study the type of cues required to gain optimum spatial information from a virtual environment. As outlined in chapter four, the inclusion of too many cues may distract from the task, but on the other hand too few, or irrelevant, cues may limit the spatial knowledge acquired (see Lintern, Roscoe, Koonce and Segal 1990; Regian and Schneider, 1990; Wickens and Baker, 1995).

In chapter one the depth cues that combine to determine perceived distance were discussed. Cutting (1997) suggests that individual differences in depth perception of VE’s may be found. He proposes that although there are many depth cues, individuals may favour some sources of depth information over others. Thus there may be differences in knowledge gained from a VE, dependent on the depth cues available within the simulation. In the present studies desktop systems were used which provide
monocular depth cues such as relative size, occlusion and relative height. However split binocular presentations are possible with desktop VR which allow true stereoscopic viewing (see Chapters 1 and 2).

Although one of the positive qualities of virtual environments is the interactivity involved, compared to media such as video, the level of interactivity that is appropriate for specific tasks also needs to be considered. Interactivity with objects within the environment may distract the user. For instance, in the small scale environments used in Experiment eight, the children sometimes seemed to be more interested in interacting with the calculator and light switches than exploring the overall environment. The level of interactivity needs to be varied depending on the task in hand. However it should always be borne in mind that the environment should be sufficiently stimulating in order to maintain the user's attention. One of the benefits of VR in therapy is the interactivity and excitement provided for the user compared with conventional therapies (see Wann, 1996; Wilson, Foreman and Stanton, in press(b)).

As some studies have found that the skills learned in the course of training disappear after the training has ceased (Davies & Rogers, 1985; Robertson, Richardson & Youngson, 1984), the durability and generality of the spatial knowledge acquired using a simulation needs to be assessed. Furthermore, does spatial information learned via exploration of a simulated building last as long as the equivalent information learned in the real building? Does spatial information learned in a simulation transfer to buildings in general or just to the particular building explored in simulation?
Experiments 7-9 have shown an improvement in skill within VE’s after VR exposure. Although these results provide strong evidence for transfer of skill within VE’s, transfer to real buildings needs to be examined. Further studies might also examine what aspects of behaviour change following virtual exploration (alertness, attention to cues etc.). A pilot study has shown that spatial information gained using the Ash Field school simulation (Experiment 6) was retained over seven months by some of the children. As VE’s are “open to further design,” (Earnshaw and Vince, 1995, p.xxi) it is essential that simulated environments built to represent real world places, are updated in order to ensure currency and avoid negative transfer effects.

Research to date has usually involved single tier environments, but when environments on more than one level have been used, vertical spatial encoding has been found to be comparatively poor (Wilson et al, 1996). There is little evidence to suggest that mental representations acquired from computer-simulated navigation contain information from the vertical plane. The environments that were used in the present studies are all one level (most special schools are just one storey buildings), but in their daily life and especially as they grow older, children will encounter more and more complex buildings with many levels (office blocks, shopping centres, car parks), so it is important that childrens’ spatial abilities are not restricted to horizontal spatial relationships. Wilson et al (1996) suggest that children may have had difficulties estimating the position of objects from floor to floor due to problems with the type of simulation, rather than the spatial knowledge of the children. However, there are other possible explanations, such as a general lack of vertical scanning taking place. Perhaps individuals are used to scanning horizontally but not vertically.
This form of scanning could be further reduced using a desktop simulation, as more effort is required to move the viewpoint up and down whilst moving around the environment, due to the limited field of view afforded by the screen display.

Different exploration strategies could be investigated to examine whether some are more effective than others. Gaunet and Thinus-Blanc (1996), in their study of spatial skills in blind participants, have observed two different forms of exploration in laboratory tasks, one involving cyclical movements around a stimulus array and one showing back and forth patterns between specific object pairs. They suggest that individuals may use particular strategies when exploring and some of these strategies may result in a more accurate internal spatial representation than others. Perhaps teaching children to explore in a particular way, for example, via directing attention to significant spatial cues or scanning more frequently (see Chapter 3), may reduce the speed required to develop an effective representation of a built environment and the accuracy of the end result.

Semi-immersive VR systems (large screen displays) could be used instead of computer monitors to examine whether the wider field of view, and reduced distraction from a blank peripheral field, aids the acquisition of spatial knowledge. Perhaps now that HMD’s have become lighter and the screen resolution has been improved, some disabled children may be able to use this equipment more effectively than before. It might in future be possible to evaluate the spatial knowledge acquired when participants are more fully immersed in a virtual environment. Ruddle et al (1996) found that users took advantage of the natural head-tracked interface on the
head mounted display to look around more, and navigation took less time, than when using a desktop system, but the use of a HMD was not shown to be superior to desktop system in terms of the acquisition of spatial knowledge. However the problems of side effects when using HMD’s outlined in Chapter two, would need to be addressed if this technology is to be used by disabled children.

The effects of the degree of “presence” in a VE need to be examined. In the present studies, children seemed to be gaining a good deal of information from a desk top system. However the degree of presence has been positively correlated with subjective reporting of enjoyment. Enjoyment is suggested to be associated with better task performance, linking better task performance to a greater feeling of presence (Barfield and Weghorst, 1993). Affect has also been shown to influence spatial encoding (Herman, Miller and Shiraki, 1995). It could be that children’s skills would show added improvement if more fully immersed in an environment. This could be examined by testing children using various displays (desktop, large screen and HMD systems), and using different devices to create a sense of “presence.” For example, association and identification with a virtual body (not necessarily like the user’s real body) has been linked with a greater sense of presence in the virtual environment (Barfield, 1995b).

Thorndyke and Hayes-Roth (1982) suggest that people build up their spatial knowledge from a variety of different sources and information gained from each of these sources is integrated to form spatial knowledge. In all the studies outlined, an egocentric viewpoint only has been used. If environments are to be used for training
an exocentric (map like) viewpoint could also be presented, perhaps in a small section of the main screen (see Brooks, 1988). A link would need to be made between the location of the user and objects within the environment and their current position marked on the map. A rotating frame of reference could be used on the map in order to eliminate the problem of orientation specificity. The effects of using an egocentric rotating frame of reference with an electronic map, on the formation of a cognitive internal representation would need to be examined further before they were used with disabled children (cf. Aretz, 1991).

So far all the children in these studies have worked individually with the experimenter, however there is the potential for multi-user interaction (children working together) and also networking machines so that two children working on separate computers can both interact with each other within a shared virtual world.

"Outside (and perhaps within) academic topics, peers may fill important roles seldom taken by adults. They may be likely to foster exploration without immediate goals that in the long run lead to insightful solutions to unforeseen problems. They may encourage motivation and channel the choice of activities. And compared with the busy adults in children’s environments, other children certainly offer their availability and time.” (Tudge and Rogoff, 1989, p.35).

As Todge and Rogoff (1989) suggest, children need mutual exchange of ideas, active observation and/or joint involvement in a task. Littleton, Light, Joiner and Barnes (1992) also demonstrated that children working in pairs showed a significant
advantage over those working individually. Perhaps an even greater improvement in spatial skill is possible if information is discussed and pooled. However of course there is also the problem that one child may dominate and the other may not gain as much as if they had explored individually. One of the important aims behind the present research is to encourage autonomous exploration, and in this respect, it may prove important to work individually, at least some of the time.

In the present studies all the children explored actively via use of an appropriate interface. However the active/passive issue outlined in Chapter two needs more attention. For a greater proportion of the population of disabled children to benefit from virtual environment exploration, it is essential to examine the benefits gained from passively exploring (allowing another user to physically control movement through the environment, while still making active choices and determining direction of exploration). Examining the effects of passive exploration and/or the availability of more appropriate tailored interfaces for the more severely disabled could enable a larger population to benefit from the use of VE’s.

Finally, as technological development progresses rapidly it is essential that schools are kept up to date. The next step is to integrate VR systems into special schools and put the theory outlined in this thesis into practice. An added advantage of a VR system is that it is not limited to a single subject but can support many disciplines eg. Geography, Technology, Physics. A VR system need not be used as a substitute for real world exploration but could prove an important supplement in imparting spatial knowledge that children could put to use independently and with confidence when
negotiating real world environments. In years to come it is possible that all children could be ‘acquainted’ with new schools before they start via use of simulations. This could prove particularly useful in special schools where some children are also integrated into mainstream schools which tend to be much larger than special schools and therefore more daunting. Exploring a simulation before they enter would enable pupils to locate particular places such as the toilets or their classroom and make for an easier transition.

In Chapter two it was suggested that, “Some tasks may be uniquely suited to virtual representation” (Stanney, 1995, p.28), this indeed seems the case for the spatial navigational tasks outlined in this thesis. The present research, alongside other areas of VR research for those with disabilities (see medical applications: Barfield et al. 1995a; Bajura et al. 1992; Davies and Eriksson, 1996; Rosen, 1991, assistive devices: Harwin and Rahman, 1996 and VR applications enabling the disabled to work: Greenleaf, 1992; Instance et al. 1996) could ‘open new doors’ for those with disabilities, allowing them to lead a fuller, more interactive, independent life.
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Results Tables

Chapter 3

The number of participants who chose the correct shortest route

Experiments 1-3

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Chapter 4

Experiment 6

Angle estimation scores - between subjects effect

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Angle estimation scores - within subjects effect

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Chapter 5

Experiment 7

Median angle estimation error scores using the computer pointing device

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Median angle estimation error scores using the hand pointing device

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Experiment 8

Median angle estimation error scores using the computer pointing device

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Error scores for objects placed on an outline map

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Time Taken to find a given object

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Error scores for objects placed on a hand drawn map

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Money Road test analysis

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Shepard and Metzler analysis

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Appendix II
Test Item
Picture Plane (210 degrees) Same Shape
Depth (210 degrees) Different Shape