

VIRTUAL REALITY AND HUMAN SPATIAL COGNITION

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Doctor of Philosophy
at the University of Leicester

by

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Virtual Reality and Human Spatial Cognition

Jonathan Antony Stirk

ABSTRACT

Virtual Reality is a means of presenting multi-sensory information to an individual via a computer monitor or a head mounted device. These computer generated, three-dimensional environments allow for pseudo real-time interaction and immerse the user in a synthetic space, resulting in a feeling of 'presence'. The many uses of virtual reality are discussed, including the more recent application to psychology. Development of user friendly software packages has allowed psychologists to design virtual environments for the purpose of assessment and training, as well as to further explore psychological theories. The highly visual nature of VR allows this medium to specifically examine spatial cognition in humans. Both clinical patients and non-clinical participants were examined using a number of VR environments to assess various aspects of spatial cognition. Firstly VR was used to determine whether visuospatial deficits are present in patients with Parkinson's disease or closed head injury. The results suggest that VR can be used to assess visuospatial deficit in clinical samples. The remaining studies examined human performance in environments based upon animal maze experiments. Cue preference in multiple choice tasks was investigated and results support the suggestion that distal cues are more important than proximal ones. The final study questioned whether spatial skills learnt in a computer environment could be successfully transferred to the real world and found that this was indeed the case. All of the findings promote the use of virtual reality in a psychological setting, drawing upon the advantages that VR technology has to offer in the experimental field.

Dedicated to Susan Stirk, Jamie and Gizmo the mog

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CHAPTER 1

What is Virtual Reality?

1.1 Definitions

Virtual reality offers exciting possibilities and hence is a subject which has obtained much media attention over the years. With the fast moving momentum of modern technological advances, VR is more popular today than it ever has been and now has a constantly increasing list of applications, some of which will be discussed later in this chapter. However, because VR has been a topic that has grown out of the realms of science fiction, it is often misrepresented and misunderstood by the layperson. Films such as “Lawnmower Man” and other such movies have helped to paint a blurred picture of what VR really is, and therefore it is the job of this chapter to sift out the fact from the fiction, and to portray VR in a more scientific light, illuminating VR for what it is and what it is truly capable of. Even the scientific community has helped blur the definitions and abilities of VR. For example, Rheingold (1991) gave one such definition, which probably defines the possibilities of VR rather than the actuality;

“Imagine a wrap around television with three dimensional programmes, including three dimensional sound, and solid objects that you can pick up and manipulate, even feel with your fingers and your hands. Imagine immersing yourself in an artificial world and actively exploring it...Imagine that you are the creator as well as the consumer of your artificial experience, with the power to use a gesture or word to remould the world you see and hear and feel.”

Such definitions have helped to create misconceptions of VR and as a result, there have been many definitions that have arisen to compartmentalise what virtual reality is. Kalawsky (1993) humorously comments on this in the beginning of his book (“...as many definitions as workers in the field.”-p.7).

The actual term “Virtual Reality” was coined by the originator of VR research, Jaron Lanier, who started off working for a company which investigated interactive computer technology. Lanier is still active within this area. An alternate abbreviation for VR, which is more accurate, is VE (Virtual Environment). This helps alleviate the inherently oxymoronic nature of the term VR and also allows more flexibility in the definition, as sometimes non-real environments are used in research. There are a whole range of other terms used to refer to VR, including, artificial reality, cyberspace and visually coupled systems, but VR and VE are probably more common nowadays. The beginnings of VR technology were initiated in the 1950’s, with the development of teleoperated systems, for exploring environments that were deemed unsafe for human exploration. A teleoperated system normally consists of a robotic operator, complete with remote camera, which can be controlled by a user in a distant safe location, and who gains visual feedback from the remote camera by means of a screen or a headset. An example of a modern teleoperated system would be the control of a deep-sea underwater robot by a remote user in a submarine or diving bell.

So what is VR? For the purpose of this thesis we define VR as the presentation of computer generated, three-dimensional graphical worlds, which allow for pseudo real-time interaction by the user. [To be more precise, a *representation* of three-dimensional space is created by the use of a z-axis (a depth axis), providing a Cartesian co-ordinate system which consists of x, y and z axes.] Such graphical representations can be provided by means of numerous output devices (computer

monitors, video projections, HMDs), which will be discussed later in the technical section (section 1.3). The interactivity of the system segregates it from other forms of visual display technology (TV, video, slide projector) and is one of the defining components of a true VR system. Virtual reality therefore differs from passive observation of a computer program, by incorporating the potential for a user to interact in real-time with the environment and therefore to cause changes within that environment. This mimics our ability to operate upon our real-world environment and thus helps to create a feeling of immersion. This immersion has been termed “presence” by Steuer (1992) and can be defined as feeling “as if you are actually there”. According to Sheridan (1992), “presence is a subjective sensation...not so amenable to objective physiological definition and measurement.” It is therefore a psychological phenomenon, but one which is an integral part of a virtual reality experience. Levels of “presence” (measured subjectively) vary according to system capabilities and it is fair enough to say that at this time, no such system has been developed which could be mistaken for the real world. Whether such a level of presence will ever be achieved remains to be seen, but is often portrayed in science-fiction films (e.g. The Matrix, 1999). As well as visual, a full VR system can provide other sensory input, thus integrating visual, auditory and kinaesthetic modalities to provide the user with sensory rich environmental stimulation.

1.2 Types of Virtual Reality

There are 2 main classes of VR systems known as non-immersive and immersive respectively, although some researchers also include semi-immersive and large-scale projected systems such as the CAVE (see below). Non-immersive VR is also referred to as “desktop” VR because it can be easily implemented through a standard desktop

PC system, without the need for additional, often expensive, hardware. The degree of “reality” is often dependent upon the graphical capabilities of the system, with high-end Silicon Graphics workstations providing higher levels of “realism”. The environment is observed on a computer monitor or, in some cases, can be projected onto a larger screen or wall. One such projected VR system is the CAVE (see Cruz-Neira, Sandin, Defanti, Kenyon & Hart, 1993), which was developed at the university of Illinois. Large projected systems tend to enhance the feeling of presence.

Immersive virtual reality technology is the more expensive form of simulation experience and involves partially isolating an individual from their usual environmental stimuli. This is achieved by the use of a HMD or Head Mounted Device (sometimes referred to as a Helmet Mounted Device) which covers the user’s eyes and ears, cutting them off somewhat from the real world. Other devices may also be used in immersive VR, and these will be discussed in the next section.

1.3 The technology: Input and output.

As has already been mentioned, one of the defining features of virtual reality is that it is interactive. In order for it to be so, the user needs to have a means to act upon the system (input) and receive feedback on that action (output). Input and output devices vary according to the nature of the system (immersive versus non-immersive) and to the requirements of the task. Let us look at input and output devices in turn.

1.3.1 Input Devices

Most desktop VR systems have a keyboard and a joystick, as minimum input devices. Movement throughout the virtual space is controlled by keys on the keyboard and/or by movement of the joystick control. Other functions can also be incorporated into the software, which allow specific sequences of actions, for example, on pressing the fire

trigger of the joystick. All responses to input devices are software dependent and can be changed according to requirements. Other devices that may control the system include a standard mouse, a spaceball, a flexor or dataglove, and a bodysuit. The spaceball allows an extra axis of movement to the common mouse (that of up and down movement) and also rotation about the y-axis. The flexor or dataglove detects hand movement in real space and translates this to movement of a virtual “hand” in the VE. Finger movement detection is by means of fiber-optic cables within the glove, which respond to flexion and actual hand position is detected by an electromagnetic tracker (see section on HMD’s below). There are a number of hand tracking devices available, including the VPL Dataglove and the Mattel Power Glove (see Kalawsky, 1993, pp188-199). Some datagloves even allow tactile feedback via inflatable air pockets (alveolar structures) embedded within the material.

The bodysuit is an even more elaborate “glove” but designed for the whole body and detects movement of the limbs and trunk by means of a large number of fiber-optic and electromagnetic sensors. Such motion tracking is a highly complex task involving calculations from a number of sources to determine the body’s position in real space and then translating the information into an avatar’s¹ position in virtual space.

1.3.2 Output Devices

One of the main components of an immersive VR system is that of a Helmet Mounted Device (HMD). Instead of the virtual world being viewed via a monitor or screen, the VE is presented to the user via tiny monitors (normally LCD’s) which are placed in front of each eye. HMD’s can provide monocular, bi-ocular and stereo images to the

¹ An avatar is a computer generated human figure meant to represent the user in the virtual environment.

user. A monocular image is provided by means of a single lens and does not create as much illusion of depth as the other 2 techniques. A bi-ocular image is constructed by separate but identical images, one for each eye and finally, a stereo image is constructed with 2 different images, one for each eye view. This creates stereoscopic vision in the same way that the human visual system observes the real world.

The first HMD was constructed in 1968 by Ivan Sutherland and consisted of two cathode ray tubes attached to a headband and allowed the wearer to see wire-frame computer generated 3D objects. This HMD even included a primitive head position tracking system, but was very heavy and not portable like most of today's modern headsets.

Nowadays, lighter and smaller HMD's are available which use electromagnetic tracking systems (such as the Polhemus & Fastrak system) to determine the user's head position in real space. Tracking involves an emitter that sends out electromagnetic signals from the headset and a detector which detects the EM signal from a static position, such as the top of the computer monitor. Most headsets also provide stereo audio input by incorporating headphones within them. In non-immersive VR, stereo sound can be produced from desktop speakers and can now be directionalized using the latest 3D sound cards [see Wenzel (1991)]. Kalawsky (1993) [Chapter 4] goes into further technical detail about how these systems work and some of their shortcomings. As well as position tracking, movement tracking is also important, so that the computer environment can update its viewpoint according to real-time movements of the user's head (e.g. turning of the head to the left and right or up and down). Movement tracking is often carried out by the use of a liquid mercury tracking system, which works in a similar way to movement detection by the vestibular system of the inner ear. Movement of the head causes movement of the

heavy metal within the tracker, which in turn is detected by sensors within the apparatus and finally translated to movement data that is interpreted by the computer.

Most modern HMD's combine both position and movement tracking.

An alternative to stereoscopic viewing via a HMD is to view a desktop or semi-immersive system using a pair of LCD shutter glasses. An example of LCD glasses is the *CrystalEyes* glasses made by the Stereographics company. These are a lightweight set of glasses that can be worn over the top of the user's normal reading glasses to view stereo images on a PC monitor. The glasses have LCD lenses, one over each eye and can selectively block out the image sent to each eye by the graphical display. In order to perceive depth in the real world, our eyes send slightly different views of the world to our brains. This effect is mimicked using the stereo glasses. Two views of the virtual environment are displayed on the computer monitor in rapid succession; one view for the left eye and one for the right. At the same time as this alternation of images occurs, the LCD shutters on the lenses open and close (left and right alternating) so that when the left eye image is on the screen, the right eye shutter is closed (and the image is passed to the left eye), and when the right eye image is on the screen, the left shutter closes (and the image is passed to the right eye). This rapid passing of a stereo pair of images to alternate eyes leads to the perception of a three-dimensional environment.

1.4 Ethical Considerations

Psychological research has to abide by stringent ethical guidelines and so it is important to be aware of the potential consequences of interacting with VEs. Such consequences can be sub-divided into 3 possible side effects; *physiological*, *psychological* and *physical*.

1.4.1 Physiological Consequences

Of the physiological symptoms, motion sickness or simulator sickness are concerns, however research by Kennedy, Berbaum, Lilienthal, Dunlap, Mulligan and Funaro (1987) suggests that only 30% of people will suffer from simulator sickness in the worse simulator conditions. Simulator sickness is more common in fully immersive VR systems than in semi or non-immersive conditions and it is thought that the time lag between head movement and the HMD image being updated is a contributory factor leading to this. The vestibular information does not synchronise temporally with the visual input and this leads to sensory conflict, which in turn helps to develop symptoms of simulator sickness. One way around this is to focus on using non-immersive or semi-immersive systems to present environments to participants in psychological experiments, and this form of presentation has been used consistently with participants in the present studies, with very few reports of physiological symptoms.

According to Kolasinski (1995), simulator sickness can be due to a number of interacting factors, which can be split into three categories; individual, task and VR system factors. The individual factors cannot really be controlled for, however technology is constantly trying to improve on the VR system factors, in order to help alleviate simulator sickness. Such system factors include field of view, inter-ocular distance, flicker, position-tracking error, time lag and refresh rates.

There are a number of other potential physiological symptoms which have been documented, including postural problems, cardiovascular changes and visual problems. In terms of visual problems, eye strain is common and has been well researched in both monoscopic and stereoscopic systems [see Daum, Good & Tijerina (1988), and Howarth & Istance (1985) for work into effects of monoscopic displays].

In the series of experiments described within this work, participants spent no longer than 30-40 minutes in front of a desktop VR system which presented monoscopic environments and were always told that they could pause or withdraw if they felt the onset of any uncomfortable symptoms.

Research into the effects of wearing HMD's has also been carried out and one important factor effecting severity of visual symptoms is the mismatch between the inter pupillary distance (IPD) [distance between the two centres of a person's pupils] of the user, the inter ocular distance (IOD) [distance between the two centres of the lenses in the headset] and the inter screen distance (ISD) [distance between the two centres of the LCD screens]. Regan and Price's (1993) study suggested that the larger the difference between the IOD and the IPD, the larger the frequency of reported side-effects. Modern headsets therefore allow the inter ocular distance to be altered, so that the user can be immersed for longer periods of time without any adverse side-effects. Rushton, Mon-Williams and Wann (1994) carried out an experiment as a follow up to their previous 1993 study [Mon-Williams, Wann and Rushton (1993)] which had previously highlighted some of the negative effects of immersive VR headsets. In the later study, they tested a new generation HMD, the Visette 2000, and concluded that the new generation headsets lead to fewer visual symptoms. In fact only 6 out of 50 participants reported any visual problems with this headset and those were only short lived, temporary ones. However, in a study by Regan and Price (1994), it was found that up to 61% of participants reported having side-effects ranging from eye strain to severe nausea, when immersed in VR for a 20 minute period. It seems clear that there are so many factors influencing the onset of simulator symptoms that results are often contradictory and inconsistent.

1.4.2 Psychological Consequences

The media likes to portray the possibility of becoming psychologically addicted to VR based environments and of wanting to not come back to reality. However, there is little research looking into psychological addiction to VEs and so no experimental evidence is available to back up these media claims.

1.4.3 Physical Consequences

There have been a number of physical consequences which have been discussed (see Costello and Howarth, 1996) in relation to interacting with virtual environments. Some of these, however, can be “risks” for any human computer interaction, and are therefore not isolated to virtual reality use. Actual physical injury is a possibility, particularly when using fully immersive VR, which cuts off the usual sensory channels from the outside world. There is therefore the risk of colliding with objects in the real world, whilst being immersed in the virtual one. Precautions can be taken by experimenters to make sure that the physical space around the user is hazard free and hence minimise risk of physical injuries. The chances of physical injury can also be lowered by using augmented reality (AR), which allows virtual objects to be superimposed upon the real world, so that both real and virtual images can be viewed at the same time. Over the years there has been much focus on RSIs (Repetitive Strain Injuries), with the increase in computer use in the working environment. RSIs are another inherent risk in VEs, but it could be argued that movements in VEs are actually more naturalistic (i.e. using your “virtual hand” to pick up an object) so help to lessen the chances of RSI. Obviously the extent to which RSIs are possible is dependent on the computer-user interface. Postural problems are another possibility depending on the type of system. Immersive systems are more likely to effect posture due to the weight of the headset, however HMD’s are becoming progressively lighter,

as are the stereo-glasses. It has been suggested (So, 1994) that by remaining relatively still, an extra pressure is placed on the user's neck. An alternative to heavier headsets is to use a ceiling suspended headset, in which all the weight is supported from above (the BOOM system).

Finally, the wearing of a single headset by a number of users is a source of infection transmission and hence a possible hygiene problem. However, removable and washable headset padding can be used to remedy this.

Despite the possible consequences discussed above, VR offers possible health/medical benefits which will be discussed under the applications section later in this chapter.

1.5 Design of VR worlds

The design of virtual environments can be a complex task and is of course dependent on the specific requirements of the task. If a task is looking at transfer of spatial information from a virtual representation of an environment to a real one, then scale and realism are factors which need to be focused upon. Complexity of the environment is another factor to consider and of course the constraints of time need to be examined. Davis, Lansdown and Huxor (1996) suggest 9 recommendations (listed below) for the design of virtual environments and also discuss the factors to be considered when building them.

Summarised Recommendations of Davis et al (1996, pp 89-90)

<i>1. A variety of courses in Higher Education should teach VR in disciplines such as Computer Science, Art & Design, Psychology and Sociology.</i>
<i>2. VR projects should aim to be multi-disciplinary and involve teamwork.</i>
<i>3. Advantage should be taken of the lack of rules guiding what VEs should be like.</i>
<i>4. VR projects with educational remit should recall the criteria of educational effectiveness.</i>

5. <i>Shared worlds should be investigated to support distance learning, whilst ensuring that the social grouping effect is not lost.</i>
6. <i>A multiplicity of models and worlds are encouraged to be used by different disciplines and for different purposes.</i>
7. <i>VR creators should seek to influence new standards.</i>
8. <i>A wide range of research should be undertaken into many aspects of VR, particularly informational and educational effectiveness.</i>
9. <i>Virtual reality & reality; 5 guidelines for designers:</i> <i>a. Do not mimic reality without a good reason.</i> <i>b. Be selective- use detail only when it serves a purpose.</i> <i>c. If reality is required, suggest it by carefully chosen items together with simple forms.</i> <i>d. Harness those aspects of reality which serve the purposes of the project, suppressing those which do not</i> <i>e. Feel free to mix realism with non-realism.</i>

1.5.1 Superscape's VRT

The actual process of creating VEs can be carried out using a number of commercial software applications that have been adapted from CAD (Computer Aided Design) programs. All testing environments in the series of experiments presented here were constructed using Superscape's VRT 5 (Virtual Reality Toolkit 5) package (<http://www.superscape.com>). This software runs on a Windows 9x multimedia PC and consists of a number of editors designed to carry out various functions. Three of the most used editors are the *Shape editor*, the *world editor* and the *visualiser*.

1.5.1.1 The Shape Editor

Every single object in the virtual environment is composed of a shape or of a number of shapes fitted together to form a complete object. Within the shape editor, points (which have an x, y and z co-ordinate) are linked in three dimensional space to form flat surfaces or facets. Facets are then linked to each other to create solid shapes, such

as a cube (which consists of 6 square facets), or a pyramid, for example. Within the shape editor, facets and points can be manipulated, using the point and click graphical user interface. For example, points and/or facets can be duplicated, reflected, moved, deleted, coloured, lit etc.

1.5.1.2 The World Editor

The world editor is where the actual environment is constructed using objects that are based on shapes made in the shape editor. Within this editor, objects can be positioned, moved, deleted, duplicated, coloured, rotated, distorted and re-sized. Every single object has a world co-ordinate, which defines the position of the origin of the bounding cube, which invisibly surrounds each object. Simple objects can be grouped within an invisible cuboidal group to form more complex objects which in turn can be moved as an integrated unit. Objects that are placed within the world automatically have collision detection built in, meaning that they are solid and cannot be walked through, like objects in the real world. Within the world editor, objects can be made to move automatically when the world is first loaded or movements may be triggered when an object is clicked with the mouse cursor. For example, a door can be made to open wide when the handle is clicked by the user or a draw may close when “touched”. Sounds may also be added to an object, so that, for example, on opening a door, a creaking noise can be heard from the headphones or stereo speakers.

In order to speed up the processing of all the world objects, a process known as distancing can be implemented in the world editor. Distancing involves the gradual simplification of objects as the human viewpoint moves further away from them. Just as objects become less defined the further away we are from them in the real world, a similar effect can be achieved using distancing. As the viewpoint moves away from the object, complex shapes are replaced by simpler ones and the reverse occurs as the

viewpoint approaches the object. At a fixed distance from the viewpoint, an entire object or group of objects can be made to disappear, which in turn allows the world to be rendered faster and therefore run more smoothly.

Also within this editor, objects and events can be programmed using a language very similar to C++, known as SCL (Superscape Control Language). SCL is the backbone to the point and click graphical user interface of the main VRT editors.

1.5.1.3 The Visualiser

The visualiser is a run-time component of VRT, which means that it can be used as a separate program to view virtual environments. Some versions of the visualiser are freely distributed with trial versions available over the internet. This allows users to view worlds created in VRT without having to purchase the full editing software itself. Within the visualiser, users can navigate through a virtual environment and interact with it but do not have editing privileges. Only certain predefined elements can be changed, such as the movement step size or the size of the viewing window, for example. The visualiser is an end-user platform with limited functionality compared with the full VRT software, but serves its function in allowing distributed virtual worlds to be viewed (visualised). Superscape now also supports a program called *Viscape*, which is a plug-in for web browsers (such as Netscape Communicator and Internet Explorer). This acts in a similar way to the visualiser, but allows the user to interact with virtual simulations directly over the internet. One famous web environment is that of the *Virtual Stonehenge* (see section 1.6.4 for further information about this environment), created by Intel (follow links from <http://www.intel.com> to view the simulation), which can be viewed through a Viscape enhanced browser.

1.5.1.4 The Other Editors

The remaining components of VRT include a sound editor, used to create and manipulate sounds attached to events, an image editor, used to edit images for texture mapping, a layout editor, a keyboard editor and a resource editor. The layout editor is used to alter the arrangement of the viewing window(s). The keyboard editor is used to assign functions to specific keys or combinations of keys, and the resource editor is used to create dialog boxes and menu controls.

1.5.2 Other VR Software

Although Superscape's VRT has been used consistently in the following experiments, other software is available to design VEs. Of these packages, World Tool Kit (WTK) developed by the Sense8 Corporation is one of the best-known alternatives to VRT (see <http://www.sense8.com> for technical details and further information). Another piece of software, commercially available, is Domark's 3D Construction kit, which allows direct manipulation of objects using a point and click interface. Further examples include the Minimal Reality (MR) Toolkit and Realimation (see <http://www.realimation.com>) designed to be used on high-end systems such as a Silicon Graphics workstation or SUN system.

1.6 Applications of Virtual Environments

Over the years, virtual environments have been developed for a number of uses and applications. They were originally used by the armed forces and space industry to train pilots in simulated aeroplanes and rockets/spacecraft, as initially only these highly funded groups could finance the software and hardware required. However, with the development of commercially available software and with the drop in costs for computer hardware, virtual reality technology was soon firmly grasped in the

hands of academic research teams and further applications were explored. There are now many avenues of VR research which can be taken and this section will summarise some of those research paths.

1.6.1 The Leisure/Games Industry

One other highly financed group, besides the military, is the leisure industry. Some of the most popular computer games of the last few years have been those based on a 3D graphics engine. These include games such as DOOM, Heretic and, more recently, Tomb Raider. All these games use three-dimensional environments within which the player can navigate and act upon. The environments frequently contain traps, monsters and various collectable items and, more often than not, the aim is to kill the monsters and eventually exit the maze-like corridors of the environment without losing your life! These games differ greatly from the 2-dimensional “platform” games, in that they create a feeling of “presence” which is also aided by the stereo quality directionalised sound effects.

1.6.2 Education & Training

The fall in prices for VR technology and the integration of Information Technology into mainstream education has brought about the application of VEs in the learning environment. Increasing pressure on teachers and the educational system as a whole has led to new ways of teaching being explored. In the USA, VR has been applied to a whole range of activities in secondary and higher educational institutions. Kalawsky (1996) states that "...VR has the potential to revolutionise education, particularly the higher education establishments." but he also warns that an understanding of where and how to apply VR is important. Kalawsky discusses a number of features which make VR an ideal tool for education; Stuart and Thomas (1991) provide a number of examples of the potential use of VR environments in the main stream classroom, including the ability for students to explore places which would normally be inaccessible or dangerous, such as oceans or the jungle. An example of VR as an educational tool is Science World [see Dede, Salzman, Loftin & Ash (1997)]. This series of environments teach scientific concepts by taking advantage of the multi-sensory nature of the software. This multi-sensory approach is superior to conventional teaching, which according to Halloun & Hestenes (1985) has been shown to lead to inaccurate mental models. VIRART (Virtual Reality Applications Research Team) at Nottingham University have also looked at the educational benefits of VR and have developed an environment to teach students about LASER physics.

These are examples applied to mainstream students, however a great deal of research has been undertaken which looks at teaching and skills training for special needs students/children. Powers and Darrow (1994) state that "...virtual reality holds special promise for empowering the lives of persons with disabilities" and Cromby (1996)

suggested that VEs promote self-directed or active learning (Standen and Low (1996) which has been found to be an important factor in the development of perceptual abilities (Held & Hein, 1963).

Strickland, Marcus, Hogan, Mesibov & McAllister (1995) used a VR environment to teach autistic children safe road-crossing behaviour, whereas Cromby, Standen, Newman and Tasker (1996) used a “virtual supermarket” to determine how well tasks learnt in a virtual environment transferred to the real world. Their VR trained group outperformed a control group when finding four items from a list in the real supermarket and also performed more quickly and with a higher degree of accuracy. A further study, by Standen and Low (1996), looked at the teaching of Makaton symbols (used in special schools to represent words and actions) using a virtual environment. The results strongly suggested that self-directed activity is greatly encouraged when learning disabled children interact with virtual reality based teaching environments.

VR also has a place in the teaching of language. Taylor (1992) suggests that VR offers enormous potential in teaching language and states that students could even create their own teaching environments. Rose (1996a) discusses the use of VR in relation to teaching languages and ran a study at HITL (University of Washington) using his *Zengo Sayu* environment that aimed to teach the Japanese language [see Rose (1996b)]. He concluded that language could be taught through a virtual medium. It can be seen from the above examples that VR technology has a great deal to offer the education system, however, the potential side-effects presented earlier in this chapter have to be born in mind, as well as other possible problems. The user interface is something that has to be considered, particularly when people with physical disabilities are required to interact with virtual environments. Middleton (1992) has

suggested that one should look at what an individual can do and control the best and then use this as a means to control the program. Ethical problems associated with children and VR have also been broached. The actual content of VEs could lead to social problems in children, particularly in gaming type VR environments. Calvert and Tan (1994) showed that exposure of children to a violent desktop VE game led to higher levels of arousal and an increase in aggressive thought. One other issue is the misuse of VR. For example, a virtual sex education program could be used for sexual gratification or amusement instead of education. Another criticism has been that of the potential for VEs to weaken an individual's sense of what is real (although this probably applies more to fully immersive systems than to desktop ones), that is to distort our reality testing procedures. According to Whalley (1993), this distortion of reality is more hazardous in those people whose reality may already be distorted (for example, those people who may be suffering from psychological disorders). Finally, it is possible that interaction with a virtual environment may result in social isolation, with children preferring the VE to the real world, and thus minimising communications with real people. Despite the above-mentioned considerations, the educational benefits of virtual reality are apparent.

1.6.3 Art & Design

Virtual reality was partially developed from commercial CAD (Computer Aided Design) programs, used in the design industry for modelling cars, buildings etc. It therefore continues to have applications in these areas.

Within the design industry VR has been used to allow designers and end-users to visualise complex models, such as machinery or building interiors. VR based CAD systems allow the designers to actually place themselves in their designs and hence

examine them for human factor considerations, ergonomic issues and possibly for ease of assembly. VR adds greatly to a conventional CAD system by including the potential to interact in real time with the model using a data glove or other hand-held device. This idea was demonstrated by the Rover Group, using their Rover 400 car interior design project, which was developed in association with British Aerospace. A VR model of the interior of the Rover 400 was constructed using various software programs and together with an immersive headset, the designer could reach out using a virtual hand (controlled by a dataglove) and re-design the interior elements of the car. The system allowed the user to move design elements around and to change submodalities of the elements, such as size and colour.

Another example of virtual reality design, one with which the reader can have first hand experience [by visiting the web site <http://www.whirlpool.com/virtualkitchen/> (requires Superscape's Viscap browser plugin)], is that used by Whirlpool, to help prospective kitchen buyers plan and lay out their own kitchen. This environment consists of a number of interchangeable elements that one would find in a normal kitchen. These include cupboards, ovens, microwaves, dishwashers, washing machines, fridges, freezers and spin dryers. All of these elements can be moved around, slotted into the available space and changed colour, in order to design ones own kitchen. The environment is controlled using a web page interface that also provides textual information about the various features of the kitchen (e.g. prices, dimensions, available colours etc.). With these types of environment, it is possible that design may well become a paperless task. Shaw (1992) has already suggested this with respect to the design of aircraft.

Superscape, the company who created VRT 5, has released a children's version of their software, in collaboration with Lego, known as the *Lego Creator*. It is, in

summary, a design play tool that allows the user to create virtual worlds out of Lego-like building blocks. Objects can be made to move and animate, and many other functions can be performed using an easy to manage, intuitive graphical interface. Such a tool allows children to learn about constructing buildings and virtual spaces and further develops a well used and much enjoyed children's product.

It has also been argued that VR has a role to play in modern art as a form of expression. Many forms of art have the ability to immerse the viewer to some extent, but VR, or at least the immersive version of VR, has the ability to cut off the external world's visual and auditory input (and sometimes the kinaesthetic to some degree). These multimedia experiences can be used to express the feelings of the artist and, in some cases, can be used to communicate feelings and emotions. The closest parallel to such a multimedia interaction with the art world is the experience of a "happening". A "happening" is an artist created situation that can be interacted with directly by an observer. People are asked to become a part of the situation and to experience it. Visual, auditory and tactile mediums are used to help create the "happening", much in the same way as an immersive VR system. VR art is however a unique art form.

Because of the inherently graphical nature of virtual reality, the presence of VR on the internet can in itself be considered a form of art. With the creation of Viscap (see section 1.5.1.3), VR environments can be experienced by anyone with a web browser and many graphical artists have used this medium as a method of distributing their work. There are a large number of virtual environments available through the Internet that serve no purpose other than to be explored. They can therefore be considered works of art as opposed to functional worlds, although in a sense their *function* is to be 'experienced'.

Of course the predominant means of distribution of art in society is the museum. As a museum is simply a building containing displays of art, there is no reason why these environments cannot be recreated using VR software, and this is exactly what some designers have done. For example a museum of Andy Warhol exhibits can be viewed at <http://johnson64.simplenet.com/warhol/index.html> and a 20th century aerospace museum can be explored (using the QuickTime VR plugin) at <http://www.sacmuseum.org/exh-qtvr.html>. There are many more sites available to browse on the web, most of which require a VRML (Virtual Reality Mark-up Language) enhanced browser.

1.6.4 Real spaces and social spaces

Virtual reality creates virtual space, and this virtual space can be based on real places or can be completely fabricated. The ability to create virtual museums based on the *real* thing has already been mentioned above. One other advantage of VR is that the historical progression of a place can be examined. To make this clearer, we will examine more closely the example of *Virtual Stonehenge* (found at <http://www.connectedpc.com/cpc/explore/stonehenge/index.htm>) referred to in section 1.5.1.3. The Intel model of Stonehenge allows the user to view the ancient monument through 10 different eras [Era 1 - Mesolithic activity (8500-6700BC) through to Era 10 - Future Stonehenge]. As the user progresses through the 10 periods of history so the development of Stonehenge can be observed. This environment therefore also acts as a teaching tool. A further example of a real space is the 3D model of the Taj Mahal (<http://www.intel.com/apac/eng/tajmahal/model.htm>) with many other 3D models of real-world places on the internet.

Virtual reality models have also allowed various advances in computer-mediated communication technology. Early on in the development of the internet, a number of social spaces appeared in the form of MUDs (Multi User Domains) which were text based ‘worlds’ in which logged-in users could explore and communicate. Users could hold conversations with other users via the internet in an artificial reality. VR environments now allow similar social spaces to be developed, but ones which draw more heavily upon the graphical capabilities of modern home computers. One such experimental environment is the *Virtual Playground* being developed at the HIT Lab in Washington by Schwartz, Bricker, Campbell, Furness, Inkpen, Matheson, Nakamura, Shen, Tanney and Yeh (1998). The Virtual Playground was developed in order to examine how people learn, perform co-operative work and engage in entertaining activities within a shared and distributed three-dimensional environment. It is a long-term study which continues the *GreenSpace* project (also ran by the HIT Lab). One of the teams’ aims was to develop a social space that could be run on relatively inexpensive home PC systems using Java based programming, which is compatible with most world wide web browsers.

In their paper, four types of validity of the social space are considered;

1. *Economic validity*
2. *Technical validity*
3. *Spatial validity*
4. *Social validity*

Economic validity involves considering the costs associated with maintaining such an environment and how these costs are met. Costs include the cost for the user to be able to use the system (i.e. cost of the PC and ISP connection) and costs incurred to maintain the system. Schwartz et al (1998) discuss the ability to “rent out” virtual

space to business users by incorporating an electronic shopping mall within which the company's products can be sold via the net. This in turn generates revenue that helps maintain the space.

Technical validity looks at the usability of the system and technical considerations such as the latency of the system. Latency involves how fast messages are passed from host to host about things such as movement of "people" within the virtual space. It also considers the speed at which communication occurs and looks at the technical aspects of text based and audio based messaging.

Spatial validity examines the design issues in creating virtual spaces. These include how the design relates to the usability and interactivity of the environment, the digital geometry and the general aesthetics of the world.

Fourthly, social validity is discussed. Social aspects include how a person is represented in the environment (coloured avatars represent each real person in the Virtual Playground) as this affects the way people might perceive each other. The way individual differences such as gender and race are included is yet another social aspect which must be considered.

One other potential application of virtual reality is in the construction of spaces which store and allow access to information. Two examples are *StackSpace* and *InfraSpace*, described by John Waterworth. For further information on 3D worlds for information exploration, see Waterworth (1997).

1.6.5 Medicine and surgery

Probably one of the more recent developments in VR technology has been the application to medicine, more specifically surgical medicine. There is a wide range of medical applications of VR which include planning of surgery, remote and local

surgery, medical training/education and a whole range of psychological treatments (which will be discussed in Chapter 2).

VR can assist surgeons by adding to or complementing data from other medical sources (e.g. scan data) and can be used to help plan, perform and simulate surgery. Planning of surgery needs to be fast and software must be multimodal, specifically that it needs to be able to take various sources of information about a patient and integrate them into a visual whole. The *Radionics' StereoPlan* system (see <http://www.radionics.com/products/> for further surgical planning systems) is an example of a VR system used to plan neurosurgery; other systems are used to plan radiosurgery and keyhole surgery.

With respect to aiding surgery, VR systems can be used to superimpose visual data onto a real person in the form of augmented reality [See Azuma (1997) for further applications of AR and potential problems], a procedure referred to as 'image guided surgery'. Thirdly, VR is an ideal tool to educate and train medical students and specialists. It is useful for education about any three-dimensional structure and so can be used to teach about anatomical structures in the body without the need to examine cadavers directly. It offers the benefits of being available at any time and in any place where computer equipment is available, lowering the costs and risks associated with training. In the operating theatre VR can reduce the time of actual operations.

Finally, VR gives the individual the ability to carry out surgical procedures and view medical data from a remote location ('telemedicine'), another potential and practical application of VR in medicine. This is in the early stages of development, however the use of VR in remote diagnosis of individual cases by spatially separated medical experts is more feasible. Telemedicine is something that is likely to take off over the next few years, as the technology continues to expand.

1.7 Summary

This chapter has aimed to be an introduction to virtual reality and what it is. It has defined what VR is and discussed the 2 main types of VR exploration (Non-immersive (desk-top) & immersive). The types of technology were then discussed, giving an overview of the current state of VR input/output devices. The ethical nature of VR is often a concern, and so some ethical issues were considered. After some information about how VR worlds are created, this chapter moved on to briefly describe some of the potential applications of virtual reality including applications to the games industry, education & training and medicine.

Chapter 2 will turn to discussing aspects of spatial cognition which have been examined using virtual reality techniques and will also examine some of the other psychological applications of virtual reality.

CHAPTER 2

Spatial Cognition, Virtual Reality and Psychology

2.1 Introduction and cognitive mapping

Chapter 1 has introduced the reader to virtual reality, what it is and some of its uses to date. The following chapter will look more closely at spatial cognition and how VR can be used to explore it. The second part of the chapter will examine some current psychological applications of virtual reality technology.

This work is about spatial cognition, however such a simple statement does not express the complexity of the term. We are born into a world containing three, and arguably four, dimensions through which we must navigate in order to find food and survive. Prior to navigating space, we must first perceive it through our senses. Although our visual system is a primary component of such spatial perceptions, our other senses are used to take in spatial information. For example, the direction of a singing bird (relative to an egocentric frame of reference) could be perceived through both our visual and our auditory senses. Alternatively, locations of objects on a tray could be identified by the sense of touch. However, visuospatial cognition involves more than just perception of space itself. It also involves the encoding of space into a mental representation.

Normally these representations are based upon our navigation of real space, perceived directly through our five senses. However, we can also form representations through verbal descriptions of space [see Regian (1986)] or from two dimensional maps [see also Regian (1986)] and so direct perception of the world is not always necessary in order to create a mental construction of an environment.

A virtual environment may be considered a form of three-dimensional map, more representative of the space on which it is based than an overhead plan or map might be. Virtual environments, just like maps, maybe based on real places or may be based on completely imagined environments i.e. ones which do not exist within the real world. Navigation through a virtual space differs from navigation in real world space in a number of ways that will be discussed later (see section 2.4.3.1). In a sense, such a mental representation is similar to the way we attempt to represent space on a physical map, however such an analogy is no doubt a considerable simplification and perhaps only one way of encoding space.

According to McCarthy & Warrington (1990) there are four key pieces of information that we need to know about the world for us to be able to navigate it successfully. We need to know the locations of objects with respect to ourselves. This involves an egocentric frame of reference also known as a body-centred frame [see Brewer & Pears (1993), also Klatzky (1998)]. For example, we may need to know that the emergency cord is to our left and the pit of snakes is directly in front of us! We need to know about the location of objects in relation to other objects in our environment (may involve either an egocentric or allocentric frame of reference). For example, the money is in the safe (allocentric), or the cat is to the left of the dog (egocentric). Thirdly, it is important that we can anticipate and appreciate the relative locations of dynamic objects (e.g. a moving car) in order to avoid collisions and finally all this information needs to be stored in memory so that we don't have to constantly re-learn every environment that we encounter.

Spatial ability can therefore be defined as a process which involves the perception of spatial order and spatial relationships, normally within the real world, however, as the current work focuses on virtual environments we can broaden this definition to

include spatial relationships in VR worlds. By relationships, we include information about position, magnitude, direction, form and distance. Both real and virtual environments contain multiple objects which exist in definable spatial interrelationships and our ability to perceive and respond to these relationships can be described as spatial ability.

This definition is by no means global within cognitive psychology and one will find numerous definitions of what is meant by 'spatial' throughout the literature. Even the term 'cognition' has been given numerous definitions [see Toates (1994)]. Toates (1994) suggests that a cognitive process involves the assimilation, storage and utilization of knowledge. Foreman & Gillett (1997) state that "...terms such as spatial skill, spatial cognition, spatial memory and visual-spatial ability are all loosely used to cover a wide range of abilities that probably have different functions [and] different representations in the brain." Linn & Petersen (1985) define spatial ability as referring to "...skill in representing, transforming, generating, and recalling symbolic, non-linguistic information." (p. 1482). This definition looks upon 'spatial' as regarding information that cannot be easily represented linguistically.

Despite the inconsistencies in defining what spatial cognition is psychologists have historically chosen to explore it in two major ways. The first main approach has been to look at spatial cognition in animals (mainly in rodents) and then generalise the results to the human species. Studies from as early as 1931 [Shepard, 1931] have been used to help develop theories proposing how animals learn about the spatial structure of their environments. However the publication of the now infamous paper on cognitive maps by Tolman (1948) lead to research being focused on proving or disproving his hypothesis. Tolman suggested that animals and humans store spatial information in the form of a mental representation in the brain that bares a

resemblance to a visual map. He suggested that spatial knowledge could be gained through latent learning, that is, behaviours which are not rewarded. This contradicted the behaviourist theories of space such as Hull's drive reduction theory of spatial behaviour and was considered a direct attack on the behaviourist schools of thought. This map hypothesis has often been mistaken as being a proven construct within the brain, however it is still a theoretical construct, but probably the most accepted of the alternatives. Much research is still being undertaken to help develop ideas about the quality, form and content of the 'cognitive map'. Tolman (1948) defined a cognitive map as being similar to a field map which is formed in an animal's brain and then elaborated upon, however his definition was a little fuzzy at the edges and has since been re-examined and redefined by the work of O'Keefe and Nadel (1978).

O'Keefe and Nadel (1978) in their pioneering book '*The hippocampus as a cognitive map*' define two major systems used to represent spatial knowledge. They discuss the *taxon system*, which focuses on the use of routes to navigate through physical space, and also the *locale system*, which is a map-based system involving the production of a cognitive map-like representation of space. A taxon system involves forming sequences of information about which directions to take in response to fixed landmarks. For example, "Turn left at the traffic lights and then right at the petrol station" is an example of a highly simplified route. They also discuss the use of what they term as 'guidances' which are defined as something that "...directs attention to a particular landmark or object and requires that the rambler approach it or maintain a certain egocentric relationship to it, regardless of the behaviour involved." [O'Keefe & Nadel (1978) p. 82]. According to Foreman & Gillet (1997, p. 10) a guidance is steered in relation to a distant landmark and is only of use when the landmark is visible to the observer. A taxon system has its advantages when it comes to

information processing as such systems can be executed quickly, however they are defined by a strict serial structure which when interrupted can lead to errors in navigation. This lack of plasticity leads to an inflexible system which is prone to interruption and is not context dependent. Routes are based upon an egocentric representation of space.

The locale system is based upon an allocentric representation of space and therefore is independent of the observer's position. It is also much more flexible than the taxon system and hence more resistant to loss of information due to its high content information and redundancy. However when we talk of a map, just what do we mean? O'Keefe & Nadel (1978) define a map as "...the representation of a set of connected places which are systematically related to each other by a group of spatial transformation rules." (p. 86). However, the map is not the same as the territory, and they also point out that our representation may have metric distortions (such as distorted angle and distance relationships) that lead to a cartoon-like representation of the world. Hence, a cognitive map is not an accurately scaled model of the real world stored in our heads, but merely a version of it which is normally accurate enough for us to be able to use it to help make spatial judgements. Like maps on paper, our cognitive maps are updated, but in a more consistent manner, allowing any changes in the real world environment to be updated in the mental representation of it. O'Keefe & Nadel suggest that exploratory behaviours lead to the updating of our maps and that incongruent maps lead to active exploration in order to acquire new spatial information. Cognitive spatial representations are therefore dynamic in structure, being constantly added to and subtracted from. They can also be constructed in the absence of direct visual experience as discussed by Rieser, Lockman & Herbert (1980), who examined spatial representations in blind participants. They suggested

that prior visual experience helped in the formation of a cognitive map and that “...both specific and general visual experience play roles in representing space.”

2.2 Spatial abilities in animals (the classic paradigms)

Tolman’s (1948) concept of a cognitive map led to an increase in research into spatial cognition in animals and the development of two major animal paradigms, that of the *radial arm maze* developed by Olton & Samuelson (1976) and the *water maze* developed by Morris (1981). In the radial maze, animals have to learn to remember the locations of a subset of maze arms baited with food in order to avoid visiting non-baited arms. In the water maze animals have to swim around a circular pool of water in order to find a submerged platform that will allow them to escape the water. These two animal paradigms, along with the work of O’Keefe & Nadel, helped to integrate both behavioural and neurological approaches to spatial cognition into a structured and integrated framework.

Two of the most common theories about how animals solve the radial maze are the ‘list’ theory [Olton (1978), Brown (1992)] and the cognitive map theory [O’Keefe & Nadel (1978)]. Olton (1977) discusses a number of experiments using his radial maze paradigm which aimed to discover how rodents perform when learning to discriminate between visited and un-visited arms. His initial explanations for how rats’ performance is above chance expectation involved identifying the positions of chosen arms by comparing them with visible room landmarks and by the use of a simple strategy or rule which could be stored in working memory. Such a simple strategy could involve an algorithm such as ‘choose adjacent arms and move round in a clockwise direction’. Olton & Collison (1979) also examined the possibility of olfactory labels being used to mark visited arms and concluded, by rotating the maze

arms with respect to room cues, that olfactory cues were not used. Further work (see Olton, 1977) suggested that the hippocampal region of the brain is partly responsible for the storage of spatial memory. From his work on radial maze performance, Olton (1978) argued that the radial maze could be solved by storing a list of items in short-term working memory. Each maze arm, which can be identified by its association with room cues, is treated as a separate location, independent of the other arms (in contrast with the cognitive map hypothesis below). Olton (1978) stated that the maze “...can be successfully performed by treating each arm as an isolated stimulus, completely independent of each of the others” (p. 356). As each successive arm is investigated, it is compared with the list of already visited locations to determine whether it is one of the ‘already visited’ sub-set or not, and this is repeated for each subsequent choice.

In contrast with the Olton hypothesis is the cognitive map theory of radial maze performance (O’Keefe & Nadel, 1978). This theory suggests that each maze arm is a distinct location or place which is remembered with respect to its relationship with other ‘places’. A whole configuration is hypothesised to be stored in memory along with the status of each arm (i.e. whether it has been visited or not). Reference to the stored cognitive map should allow locations which have *not* yet been visited to be identified, without having to view the extra-maze cues. This knowledge about *where* visited and un-visited arms are should lead to rats being able to quickly move from one baited arm to the next. However, Brown (1992) explains that this is not the case. Rodents placed in the maze seem to spend a considerable amount of ‘thinking time’ on the central platform, without simply navigating from arm to arm. Instead, the rats exhibit ‘visual orientation’ towards maze arms, irrespective of their visited or un-

visited status. Tolman (1948) had previously observed this in his experiments and had termed it 'vicarious trial and error'.

Visual orientation towards a maze arm was termed a 'microchoice' by Brown, Wheeler & Riley (1989), which in turn may be followed by a visit to an arm, termed a 'macrochoice'. Each microchoice is regarded as the rat making a go-no-go decision, that is, choosing whether to go down the arm or to reject it. In two experiments investigating this 'microchoice' and 'macrochoice' behaviour, Brown (1992) observed that the frequency of microchoices increased prior to making a macrochoice as the trial progressed. This is not consistent with the predictions made from a cognitive map hypothesis, but does support those based on Olton's list theory. As a trial proceeds, the number of baited locations becomes smaller resulting in a larger number of maze arms to examine before making a macrochoice. Also in support of the list theory, Brown (1992) ran a computer simulation of choice behaviour in a radial arm maze which was programmed on the basis of assumptions from the Olton list hypothesis. His results showed that the simulation performed only slightly less well than the rats in a real maze did, suggesting that a cognitive map was not necessary to complete the maze.

The work of Brown (1992) does not suggest that a cognitive map doesn't play a role in choice behaviour in the radial arm maze, but that the status of an arm may not be stored as part of an existing map. Brown's data certainly strongly implies that a cognitive map is not the only reference system that can be used in multiple-choice search tasks.

With respect to the Morris Water Maze (1981), the consensus of opinion is that distal cues surrounding the pool serve as a mechanism for guiding navigation to the hidden platform. Distal cues have been shown to be involved by numerous researchers

including Sutherland & Dyck (1984) and Rudy, Stadler-Morris & Albert (1987), implying that a cognitive map is used to solve the task. Some animals with impaired hippocampal function (e.g. lesioned rats) resort to using other strategies such as swimming a fixed distance from the wall, suggesting that the hippocampus is indeed the seat of the cognitive map. Other researchers [e.g. Arolfo, Nera, Schenk & Bures (1994)] have investigated at what stage during navigation the available visual information is used. General findings suggest that animals rely on information collected en route.

The concepts of the radial arm maze and the water maze will be revisited at the beginning of Chapter 4. The experiments in Chapters 4 and 5 of this thesis have stemmed from these two major animal paradigms, but have been adapted for the purposes of testing humans instead of rodents. Chapter 5 uses a locomotor maze environment which is based upon both the radial and the water maze.

2.3 Clinical approaches to spatial cognition

The second major approach to exploring spatial cognition has been to look at human clinical studies of patients with spatial deficits. Studies of patients with specific brain lesions have helped to localise elements of spatial functioning within the human brain, in the same way as neuro-behavioural studies of animals with brain lesions have been used to develop models of animal spatial cognition.

2.3.1 Clinical spatial disorders

Observations of spatial disorders stem as far back as the 1800's when Jackson (1876) reported the case of a woman who after 30 years of walking a particular route,

suddenly found that she could not find her way to a park close to her home. She was also reported to have a number of other difficulties including not recognising her friends or common everyday objects. Further reports of single case studies emerged throughout the 19th century, including a patient detected by Forster (1890) who could not draw the spatial layout of his own home or form fixed spatial routes in his head.

At the turn of the 20th century, Balint (1909) documented the case of a patient who suffered extensive disorders of spatial exploration [DeRenzi (1985)]. Although the patient's ocular movements were normal, he could not pay attention to the left hand side of visual space and had an inability to judge the relative distances of objects in his environment. This series of impairments became known as Balint's syndrome, however, after Holmes (1919) carried out studies into patients with posterior parietal lesions and discovered an almost identical syndrome, the term Balint-Holmes' syndrome is now more commonly used. The only difference between the work of Balint (1909) and Holmes (1919) was that Holmes also recorded the presence of abnormal oculomotor functioning in his clinical patients.

The four main defining factors of the condition are; apraxia of gaze, incorrect judgement of distances, misreaching (optic ataxia) and disorders of visual attention [De Renzi (1985)].

Apraxia of gaze is the inability of a patient to be able to fixate their gaze on a particular position in space and fix their eyes upon it, whereas optic ataxia is the inability to co-ordinate hand and eye whilst reaching out to touch or pick up an object. Strictly it is neither a visual nor a motor deficit, but, more accurately, can be described as an inability to co-ordinate both motor and visual information into one process. Optic ataxia can be restricted to one half of visual space or to a particular upper limb, or to any combination of these.

Disorders of visual attention include an extreme *narrowing of visual attention* and/or *unilateral neglect* (also known as hemi-inattention). Narrowing of attention is when a patient is unable to describe anything else in his/her visual field whilst focusing on a specific point in space or an object. Unilateral spatial neglect (USN) is a more severe, and also more common, form of attention deficit, in which the patient fails to notice stimuli in the visual field contralateral to the site of the brain damage. It has been the subject of much interest [see Robertson & Marshall (1993)] in clinical neuropsychology. Patients therefore neglect stimuli in either their left or their right visual field. Such neglect can be observed in patients who fail to eat food from one side of their plate or who read only the left/right hand side of a page of text. Attention to the neglected field can be redirected using dynamic stimuli (e.g. animated stimuli) as shown by Butter, Kirsch, & Reeves (1990). VR based environments could also perhaps be used with exaggerated stimuli or animated ones on the neglected side to assess whether any improvements are transferred to the real world [see Rushton, Coles & Wann (1996)].

Finally, patients may show the inability to judge which objects are near or far (incorrect judgement of distance), and have problems in determining absolute distance.

As well as disorders of single point localisation (location of specific points in space), we can observe disorders of spatial analysis or of space perception and cognition. The term *visuo-spatial agnosia* [DeRenzi (1985)] has been used to encompass a number of spatial problems involving localisation, depth perception, line orientation, spatial discrimination, shape perception and spatial thinking. Specific clinical tests have been designed to measure and assess such visuo-spatial deficits. Beaumont (1998) states that cognitive processes can be analysed by observing the dissociation of independent

processes which may accompany abnormal states. He defines an independent process by giving an example of a patient who can identify objects from drawings of them but who can't indicate the correct orientation of them, and points out that in this case object recognition and orientation rely on different cognitive processes.

Examples of visuospatial tests will be discussed below (see section 2.3.2) and Chapter 3 will examine how a virtual reality paradigm can be used to explore potential spatial deficits in two groups of clinical patients, those suffering from Parkinson's disease and those who have closed head injuries.

2.3.2 Measuring spatial deficits

Although some of the above mentioned spatial problems can be behaviourally observed, there are many sub-components of spatial ability which cannot be easily detected in a person's everyday performance. It has therefore been the task of neurology and psychometrics to develop clinical spatial tasks that can be used to assess a patient's visuo-spatial functions. Many of these tests have been normalised to control populations and used to assess the severity of damage in people with neurological damage. Because of the wide range of abilities classed under the label 'spatial', it is now more common to use batteries of tests which aim to examine differing sub-components of spatial ability. These tests are designed to be relatively easy to carry out and many of them are simple pencil and paper tasks. However, with the introduction of the personal computer in the 1960's, many clinical test procedures are now being carried out on computers, which has helped speed up the process of neurological assessment and also allowed for tighter controls over test situations. Miller (1968) reviewed some of the advantages of computer-based testing, however Wilson & McMillan (1992) carried out a more comprehensive review discussing

applications to various areas including alcohol abuse, head injury and psychiatric disorders. An example of a recent computer-based spatial battery is the Visual-Spatial Perception Test, designed by Kerkhoff & Marquardt (1996), which includes tests of line orientation, line bisection, judgement of length/distance and figure matching.

Beaumont (1998) has surveyed some of the main visuospatial clinical tests and states that isolating visuo-spatial skills is not an easy undertaking as tasks may rely on a number of skills including visual perception itself. For example, in some cases a patient who manifests the symptoms of unilateral spatial neglect maybe doing so as a result of inability to *see* the stimuli as opposed to higher level inattention. The difficulty in separating motor abilities from spatial ones is also a problem and is discussed in Chapter 3.

For the sake of completion, let us briefly summarise some of the neurological tests and batteries used to assess spatial deficits in clinical patients.

Visual abilities have been examined as sub-components of general tests of intelligence (e.g. Raven's Progressive Matrices, Block design & object assembly in the WAIS-R performance scale) however this section will focus on tests designed specifically to examine spatial functioning.

Problems of visual scanning have been investigated using tests such as the Elithorn (1955) Perceptual Maze Test. This involves the patient developing a pathway through a v-shaped lattice structure, which passes through as many marked intersection points as possible (some intersection points are marked with a black dot). The task involves more than visual perception and has been shown to be sensitive to right hemisphere lesions [Colonna & Faglioni (1966)].

Visual organisation has commonly been assessed using fragmented or incomplete drawings of objects which the patient needs to mentally complete and name.

Examples of tasks designed for this purpose include Gollin's (1960) Incomplete Figure Test [see also Foreman & Hemmings (1987) for a computer version of this], the Street Completion Test [Street (1931)] and Hooper's (1958) Visual Organisation Test [fragmented figures].

Benton, Hamsher, Varney & Spreen (1983) developed a battery of tests to measure visuospatial functions. This battery of spatial tasks has been published with psychometric norms for children, adults and brain damaged patients and includes a test of right-left orientation, a visual form discrimination task and the much used Judgement of Line Orientation Test (LOT). The LOT is used in the experiment presented in Chapter 3 and is explained in further detail there. Benton et al (1983) also designed a test to explore visual construction skills, the 3-D Block Construction test. This is used to determine if patients have constructional apraxia by having them build three models from sets of 6, 8 and 15 wooden blocks. Drawing tasks may also be used to assess visual construction.

Tests of personal and extrapersonal orientation are also standard tests used to explore visual-spatial function and include tests by Spreen and Strauss (1991), Semmes, Weinstein, Ghent & Teuber (1963) [The Personal Orientation Test, see also Weinstein (1964)]. The Money (1976) Road Map Test is used to observe extrapersonal orientation.

One more recently developed battery of spatial tests is the Visual Object and Space Perception battery [Warrington & James (1991)] which has published norms. It includes a Position Discrimination sub-test using the Dot Position Task [Warrington & James (1988)]. In this task, participants have to indicate the position of a dot in a square by referring to an identical square that contains a number of labelled positions.

Finally, tests have been developed to examine attentional deficits such as USN. The Behavioural Inattention Test battery [Wilson, Cockburn & Halligan (1987)] is probably the most used and includes letter and line cancellation tasks, line bisection and some behavioural tests, such as reading from a menu or setting the time on a clock. Ogden (1985) warns that several measures should be used when testing for neglect, as patients have been seen to display neglect on some tasks but not on others.

2.4 Psychological uses of Virtual Reality

Chapter 1 gave an account of what VR is and some of its current and potential applications. This section will now explore further psychological uses of VR along with some examples of studies into spatial cognition that have been carried out using virtual reality approaches.

2.4.1 Clinical and psychotherapeutic applications

Although it is often argued that VR environments are similar enough to real life ones for useful information to be learnt from one and transferred to the other, VR is still detached from the real world that we live in. It is this dissociation between real and virtual that has led to the development of a psychological treatment for phobias using VR environments. The classical treatment for specific anxiety disorder has been to desensitise sufferers by progressively introducing them to their feared object/situation whilst teaching them to relax. VR environments can be used as a medium through which stimuli can be presented to phobics with a controlled level of detachment.

Bullinger, Roessler & Mueller-Spahn (1998) state that “...VR promises to be an appropriate tool for perception and manipulation of spatial information...” and discuss the potential of VR in treating phobics. This team at the University of Basel,

Switzerland have collaborated with a German software lab to develop a form of VR desensitisation therapy for claustrophobics (fear of closed spaces) and acrophobics (fear of heights). They ran pilot studies on phobic and control participants, using a high-end VR system [see Bullinger (1997)]. The current environment used to treat claustrophobics was a closed room structure which had a moveable inner wall which could be closed in by the therapist. The second environment was a simulation of a 40 floor building with an outside elevator, overlooking a busy city (labelled 'Performer Town'). The pilot studies immersed non-phobic control participants and acrophobic / claustrophobic participants in the appropriate environment using a Silicon Graphics immersive VR system and measured psychological responses and physiological changes in the participants whilst changing the height of the virtual lift or the space in the virtual room. Their findings suggested that VR environments could be used to create exposure anxiety in the same way as real life phobic stimuli do. This suggests that VR can be used as a medium with which to carry out desensitisation therapy. This group has now started to investigate whether VR therapy is equivalent to, better than or inferior to traditional approaches.

Other main researchers in this area have been Max North and Barbara Rothbaum. They carried out some of the earliest pilot studies into applications of virtual reality, looking at treatment of acrophobia, aerophobia, agoraphobia, phobias of specific environments (e.g. a dark barn) and social phobia (public speaking) [see North, North & Coble (1998) for a more extensive review]. Studies carried out by North, North & Coble (1997) on aerophobia showed that participants who had been given Virtual Reality Therapy (their term) obtained a significant reduction of anxiety symptoms over the term of exposure and that this reduction lead to their patients being able to face a real world flight in a helicopter with increased comfort. Rothbaum, Hodges,

Watson, Kessler & Opdyke (1996) obtained similar results from a case study of a 42 year old woman who was given VR exposure therapy to combat her fear of flying. A post-VR-exposure flight was undertaken also by the patient, who reported lower levels of self-assessed anxiety.

Studies into the treatment of the more common phobia, acrophobia (fear of heights), have also been carried out by Rothbaum, Hodges, Kooper, Opdyke, Williford & North (1995a) and Rothbaum et al (1995b). The case report study looked at a 19 year old male student who had fear of heights and specifically of lifts. Virtual reality graded exposure was administered using an immersive system which exposed the client to a virtual representation of a lift of a 49 floor hotel in Atlanta for a period of 3 weeks (5 sessions over this period, each 35-45 minutes long). A real platform with railings was constructed to help amplify the feeling of presence created by the VR experience. This case study again showed reduced levels of anxiety and height avoidance as measured using the Attitudes Towards Heights, Distress From Fear and Acrophobia questionnaires. In their larger study of 20 college students, exposure to VR footbridges, lifts and outdoor balconies was found to reduce fear significantly in comparison to a waiting-list control group who received no VR exposure.

With regards to social phobia, North et al (1998) created a virtual lecture room (based on a real room in Clark Atlanta University) and exposed 16 social phobics to it using a complex system which included equipment which would echo the person's voice, as in a real room. Their participants showed signs of anxiety (lump in throat, sweating palms etc.) when exposed to the virtual version, suggesting that VR exposure is similar to the real experience. Once again, measures on a Subjective Unit of Disturbance questionnaire were reduced over the therapy period.

Finally, another common phobia, arachnophobia (fear of spiders) has been successfully treated using VR therapy in conjunction with tactile stimuli [Carlin, Hoffman & Weghorst (1997)]. This HITL research team used a position tracked furry toy spider in this form of mixed reality (VR visual information combined with real life tactile information) technique to desensitise a highly arachnophobic patient. 'Spider World' consisted of a virtual kitchen scene with a large brown spider in it, which could be made to move and jump by the therapist or the patient. As in the previous studies, measures of anxiety were taken during exposure and after 12 weekly sessions the patients levels of anxiety had fallen significantly. This VR experience transferred to real-life situations, allowing the patient to live her everyday life in greater comfort. Levels of presence were also assessed by the researchers who argue that presence is tantamount to successful therapy. North et al (1998) suggest that the continued experience of interacting with virtual environments increases the levels of perceived presence and that it is this increase that reduces the level of presence in the real world.

Further studies into VR and phobias can be found in the literature, and applications to other clinical symptoms such as obsessive-compulsive disorder and post-traumatic stress disorder are underway. Other examples of VR use in mental health include treatment of erectile dysfunction [Optale, Munari, Nasta, Pianon, Baldaro & Viggiano (1997)] and management of eating disorders [Riva (1997a)].

Despite the applications of VR to mental health, some limitations, that are currently being overcome, exist. Huang & Alessi (1998) point out two such classes of limitation, those involving technological factors and those involving mental health research. VR equipment is still expensive for good quality immersive and force feedback systems, as is the cost of employing specialised programmers, who have to

build complex, time-consuming worlds. Head mounted displays are still bulky and may have a restricted field of view and the levels of “reality” may be low. However, Huang et al point out that “...replication of reality is not always needed for a particular application...” (p. 64). They also discuss the problems with integrating two separate ‘research cultures’, the VR and mental health communities, in order to develop an overall standard with a shared number of guidelines. The technology side of VR already has implemented some standards such as the VRML (Virtual Reality Modelling Language).

With regards to psychotherapy, Rogers (1998) has developed a system called “Mythseeker” which is an interactive VR program that allows users to explore personal myths and depth systems. He suggests a number of potential applications including education, psychotherapy and drug rehabilitation. In this program, a therapist can appear as a virtual element of the program, guiding the patient either directly or indirectly. This application of VR is an example from the realms of humanistic psychology and is discussed further by Rogers (1994).

2.4.2 Measurement & rehabilitation of cognitive deficits

One of the more recent fields of interest for a growing number of researchers has been the potential of VR in neurological deficits rehabilitation. However, the debate about the plasticity of brain functions after physical brain damage is still very much alive, but despite the arguments against cognitive rehabilitation, work is progressing in this fascinating area.

David Rose of the University of East London has established a research group intent on exploring the applications of virtual reality to cognitive rehabilitation. Rose &

Johnson (1994) have suggested four major applications of VR in neuropsychology.

These are;

- 1. The use of VR in initially determining the consequences of brain damage,*
- 2. VR as a method of increasing a patient's interaction with an environment,*
- 3. VR as a prosthetic mechanism to aid disabled individuals, and*
- 4. VR as a means of overcoming specific impairments*

Rose, Johnson, Attree, Leadbetter & Andrews (1996) state that “Crucial to successful rehabilitation is the accurate and comprehensive assessment of the patient’s current abilities.” (p. 225). The experiments described in Chapter 3 of this work are VR tasks of this nature, designed to assess spatial deficits in clinical patients. Virtual reality offers many benefits compared to standard pen and paper tests, including assessment of skills in a more realistic environment. This helps to improve the ecological validity of neuropsychological measures, which have previously been criticised for lacking validity. However, the development of more ‘everyday’ non-VR neurological tests also received criticism of ecological validity and not being as tightly controlled as their lab counterparts [Banaji & Crowder (1989) cited in Rose et al (1996)]. Here VR neurological assessment once again offers a solution, as VR worlds allow even more stringent levels of experimental control than their real-world partners. With respect to stimulus presentation, VR allows more control and consistency of presentation as well as a means of presenting scenarios that would be otherwise impractical. The Tray Task presented in Chapter 3 is an example of a testing environment that would have been impossible to control adequately in the real world. (See Section 3.5 for further information). VR tests allow safer environments for evaluating everyday skilled behaviours, offering risk-free procedures, requiring less supervision of patients and hence reducing costs. Rose et al (1996) are keen to point out that many patients may

suffer from motor impairments that may restrict their ability to carry out neurological tests which have a heavy motor component [this is discussed with regards Parkinson's patients in Chapter 3]. They argue that VR testing allows navigation through virtual space without the need to rely on navigational motor skills. Psychological experiments which test spatial abilities in large scale environments are notoriously difficult to carry out and control in the real world, but VR offers the opportunity to examine visuospatial and navigational skills in a large scale simulation of real space. One further advantage suggested by Rose (1996) is that sensory cues can be enhanced within the environment in order to improve performance by patients whose low performance may be attributed to partial sensory loss. Such modification of sensory presentation, for example the enlargement of visual cues, can be adjusted according to the experimental paradigm and/or the patient's impairments. Despite some current disadvantages of VR such as possibility of cybersickness, VR is clearly a very useful tool which is being adopted by the neuropsychological profession.

One thing that virtual reality is definitely guilty of is attracting attention and maintaining interest. Its unique interactive properties allow it to be used as a possible substitute for environmental stimulation. This is not to say that it *should* be used instead of real stimulation but there are circumstances in which VR interaction may be of benefit. Rose, Atree, Brooks & Johnson (1998) discuss a model of VR therapy which they term 'virtual enrichment therapy' [see also Rose (1996) and Rose et al (1996)]. Rose argues that neurological damage may result in reduced cerebral arousal-activation as a result of sensory/motor impairment and that other associated problems such as a decrease in motivation and attention levels lead to a reduction in environmental interaction. Previous animal work [Rose (1988)] has shown that

environmental enrichment can lead to functional recovery from brain damage, and it is Rose's belief that this is also true in humans and certainly worthy of further investigation. Because of their ability to cognitively engage a person, he proposes that virtual environments can be used to implement environmental enrichment. However before this can be done, it is necessary to establish whether VR interaction is cognitively analogous with real-world interaction. Rose et al (1998) state that further work looking at functional imaging [positron emission topography (PET) & magnetic resonance imaging (MRI)] and VR exploration, electrophysiological studies and additional 'transfer of learning' studies need to be undertaken to determine whether this is the case. Maguire, Frith, Burgess, Donnett, & O'Keefe (1998) have looked at brain activation during exploration of a large-scale virtual environment, and reported that the areas which 'lit up' as active [measured using a PET approach to following regional cerebral blood flow] were consistent with non-VR functional imaging studies of spatial memory and navigation. These types of study back up the proposal of VR interaction being cognitively equivalent to real-world interaction.

Although still in its early stages, VR may play a role in helping people with severe disabilities. Rose et al (1996) mention the use of VR as a prosthetic device to enable people with disabilities to interact more easily with their own environment. They provide an example of a virtual simulation of a person's room / house, which they can navigate and control with minimal motor movement. With the use of robotics and electronics, actions in the virtual room are reflected by the same action in the real room, for example, the drawing of curtains. The use of networked environments may also lead to an additional means of communication, such as the 'social spaces' described in Chapter 1.

The fourth application of virtual environments is to use them to help patients to overcome specific impairments. Riess and Weghorst (1995) have used VR to help Parkinson's sufferers overcome kinesia paradoxa using an augmented reality technique (see Chapter 3 for more information on this technique). Riess (1998) discusses approaches to kinesia paradox in further detail. Brown, Standen & Cobb (1998) have applied simulations of various environments to teach disabled children to overcome some of their learning disabilities [see also Standen and Low (1996) in Chapter 1]. Rushton, Coles & Wann (1996) discuss the potential use of VR to assess and rehabilitate patients with unilateral spatial neglect. They discuss the previous approaches to rehabilitation of this deficit, such as eye patching, vestibular stimulation and optokinetic stimulation. They move on to suggest how VR could be used to superimpose kinetic stimuli on top of the real world using augmented reality as a means to shifting attention to the neglected space. See also Wann, Rushton, Smyth & Jones (1997).

Wann (1996) suggested that VEs can be used to provide a realistic context in which to rehabilitate perceptual-motor disorders following a stroke. He focuses on an application of VR to rehabilitation of hemiparesis and states that VEs can "...provide an interactive environment tailored to the needs and abilities of the patient." (P. 236). Visual feedback via a VR system tied to movement of limbs gives an additional source of information to a patient's perceptual systems which may speed up recovery and build motivation.

An interesting combination of VR and physical therapy has been suggested by Johnson, Rushton & Shaw (1996) who have linked a virtual environment to an exercise bike. Physical exercise increases cerebral arousal-activation and so this research team have developed a system in which a head injured patient has to

physically ride through a virtual landscape and carry out progressively more demanding tasks. Such interaction combined with cognitive tasks is hoped to help patients.

Rose, Attree & Brooks (1997) report 2 studies which assessed object recognition under five different conditions. VR was used to present the objects to be recognised to participants, varying the background context and motor dependence in order to tease out and analyse separate elements of a situation. Memory was seen to differ significantly in most conditions, highlighting possible discrepancies between 'everyday' memory tasks and standard neurological tasks used in assessment. A further VR experiment using stroke patients, suggested that active interaction in VEs improves spatial recognition, compared with passive observation, but that it does not effect object memory. A similar study [Attree, Brooks, Rose, Andrews, Leadbetter & Clifford (1996)] was carried out using a cohort of normal participants divided between an active and a passive group. They were tested in yoked pairs on measures of spatial memory, object memory and visual memory. The results suggested that the active group scored better for the measure of spatial layout, but on this occasion the passive group outperformed the active one on measures of object memory. A further clinical study into the active / passive debate [Pugnetti, Mendozzi, Brooks, Attree, Barbieri, Alpini, Motta & Rose (1998)] was carried out using patients diagnosed with multiple sclerosis (MS). Their results were in accordance with those of Attree et al (1996). MS patients performed worse than matched normal controls on recall of the layout of the environment, however those patients in the active condition performed better than the passive MS group. These related studies only compound the importance of using ecologically valid tests when assessing cognitive functions and

highlight the ability of VR testing procedures to “...assess aspects of spatial memory that are not measured by traditional tests.” [Pugnetti et al (1998), p. 424].

One other active researcher in the area of VR and cognitive assessment / rehabilitation is Italian psychologist Giuseppe Riva. Riva (1997b) believes that virtual reality has many advantages over conventional psychological assessment, one of the major ones being the ability to test patients in large scale realistic environments without the need to take them to real public places, where parameters are difficult to control. He considers VR to be a “...highly sophisticated form of adaptive testing.” (p. 73), with three crucial aspects. VR systems can be controlled via multiple input channels at the same time which can be translated to actions in the virtual world. They allow multimodal feedback which can be presented in many ways. Thirdly, they allow “...manipulation of multisensory representations by natural actions and gestures.” (p.74). Riva (1997b) has developed a VR tool to assess body image disturbances (BIVRS - Body Image Virtual Reality Scale) that incorporates three-dimensional models of 9 body shapes. Riva believes that the web version of BIVRS will enable results to be easily and quickly standardised and such a version can be implemented using VRML; however this restricts the advantages that immersive systems offer. Riva (1998) surveys the applications of VR in neuroscience and talks about the development of a collaborative project group, VREPAR (Virtual Reality Environments for Psycho-neuro-physiological Assessment and Rehabilitation). Such collaborative work is a good way of bringing together separate disciplines and may help in developing the much required reference standards which need to be implemented in order for VR to be more widely accepted by clinical communities. Rizzo, Buckwalter & Neumann (1997) also highlighted the need to merge a variety of

disciplines as a means of further developing the potential of VR to assess and rehabilitate patients.

Rizzo et al (1997) discuss three theoretical issues that need to be considered when looking at applications of VR to clinical settings. They point out that there may be issues of navigation within a virtual environment by patients with lessened cognitive capacities. However, as already discussed, navigation within a VE can be programmed within the means of the patients' deficits and so VR offers a flexible way of dealing with these navigation issues. None of the clinical patients in our studies (see Chapter 3) reported any problems with navigation. VR side effects are another issue raised, but once again the development of better immersive systems with less lag and better HMD's is helping to resolve problems associated with immersion. Ethical and safety issues about immersing clinical patients in virtual environments are discussed by Ring (1998) who states that "...patients with acquired neurological damage may not well understand the meaning or purpose of the three-dimensional context and be adversely affected by exposure to this technique." (p. 100). These ethical issues were discussed in detail in Chapter 1, section 1.4.

The third issue raised by Rizzo et al (1997) is that of transfer of training or adaptation [Ring (1998)]. As the interest in VR expands, the issue of whether skills learnt in a VE transfer or generalise to the real world is being resolved, with more and more studies showing transfer of skills from virtual to real. The study described in Chapter 5 clearly demonstrates that such transfer does occur. A summary of other issues pertaining to immersion in virtual environments can be found in Hamill (1994).

Finally, virtual reality opens up a whole new approach to studying the structure and functioning of areas of the brain. A typical approach to looking at cognitive deficits has been to observe direct activity in the brain, using functional brain imaging

techniques such as fMRI and PET, whilst patients are given various tasks to do. Navigational tasks have been difficult to carry out because of the patient having to remain in a fixed static location. Trepagnier (1999) argues that VR is an ideal tool which can be used to present tasks to patients, particularly those tasks that involve navigation through three-dimensional space. The study by Maguire et al (1998) mentioned above, is an example of such an application of VR to imaging studies.

2.4.3 Spatial cognition in non-clinical groups

The previous section has outlined some of the potential applications of virtual reality to clinical groups of patients, however a large amount of research has investigated spatial cognition using virtual environments in normal populations. This section will consider some of the studies that have examined spatial cognition and behaviour within virtual testing environments.

The studies that will be mentioned within this section have looked at a number of behaviours which can be classified as being spatial. For example, search tasks involving having to find target objects or locations in space, tasks involving learning and following routes, tasks investigating people's estimates of direction and bearing (configurational tasks), and tasks examining different representations of space such as maps or models. Durlach, Allen, Darken, Garnett, Loomis, Templeman & von Wiegand (2000) point out four main areas of research into spatial cognition using VR. These are

- 1. Use of VR to assess spatial abilities and skill*
- 2. Use of VR to advance fundamental understanding of spatial behaviour*
- 3. Use of virtual environments to improve spatial skills in the real world*

4. Use of VR and additional aids to improve navigational skills within virtual space.

All of the studies that follow fall into one or more of these categories.

2.4.3.1 Navigation in virtual space: Similarities and differences.

Earlier it was mentioned that the navigation of real space is essentially different to that of virtual space. Factors which vary between virtual and real environments will be now be discussed, as will some of the differences between environments presented using immersive and desktop systems.

Some of the main differences between virtual and real spaces are listed below and will then be discussed individually:

- 1. Vestibular and kinaesthetic feedback*
- 2. Field of view issues*
- 3. Previous experience*
- 4. Means of navigation*
- 5. Visual fidelity & external cues*
- 6. Levels of presence*

Vestibular and kinaesthetic feedback

Exploration of the real world normally involves movement on a number of levels. Eye movements allow the observer to perceive a certain amount of visual information and this may be extended by the turning of the head. To further learn about an environment it is normally necessary to physically navigate that environment by a means of locomotion. This would in most cases involve walking / running although may also include the use of an ambulatory device such as a wheelchair, for those people with motor difficulties. Head and body movements result in the vestibular

system sending information to the brain about the body's position in space and combined with the changes in direct visual information result in the 'feeling' of movement. In addition to vestibular information, movement of limbs results in a form of kinaesthetic or haptic feedback too. Virtual reality differs in the levels of tactile and vestibular feedback, providing less than in the real world. In non-immersive VR systems no feedback of this nature is provided as movements within the system are controlled by abstract user devices such as a joystick or spaceball. Tactile feedback is not consistent with the visual information (one explanation of so-called 'cyber-sickness') as often it is only the upper limbs that are required to control virtual body movement. In head-tracked immersive systems the visual scene is updated as a result of actual head movements and so some vestibular information is present. Ruddle, Payne & Jones (1999b) discuss differences in vestibular and kinaesthetic feedback between immersive and desk-top systems, as well as pointing out a number of other differences.

It is unclear to what extent minimal vestibular and kinaesthetic feedback effect spatial cognition, however researchers have begun to focus on developing interfaces which allow increased levels of this type of feedback. Certainly spatial information can be learnt in the absence of direct visual perception as demonstrated by Rieser, Lockman & Pick (1980) who investigated blind participants' abilities to judge distances between pairs of locations in familiar space. Their congenitally blind participants performed worse than sighted participants but performance was not completely destroyed, suggesting that kinaesthetic and vestibular factors may be involved. However the effect of other factors such as stepping strategies cannot be ruled out as a means of estimating distance.

Researchers such as Grant & Magee (1998), Chance, Gaunet, Beall & Loomis (1998) and Templeman, Denbrook & Sibert (1999) have examined the contributions of vestibular and proprioceptive feedback in navigating VEs. Grant et al (1998) used an interface which either allowed or did not allow proprioceptive feedback. Two groups of participants were assigned to either a walking or joystick interface which allowed them to navigate and learn the layout of a floor in the Ontario Science Centre. A further 3 groups were assigned to either a 'real walking' (actually walked within the real building), 'map' (shown a map of the floor) or 'no training' condition. Participants were more easily oriented in the real world environment, once again demonstrating how easily participants can lose their way in large scale virtual environments. The walking interface, which provided additional proprioceptive input, had no effect on orientation within the VR environment but when participants were tested on transfer trials in the real world building the additional kinaesthetic feedback led to significantly enhanced spatial knowledge. However, this study did not find additional effectiveness of the walking interface when a different measure of performance ('time to find destinations') was used.

Chance et al (1998) examined the input of kinaesthetic feedback on a path integration task. Their within-subjects design examined 3 modes of locomotion within a number of virtually presented mazes. In the 'walk' mode participants walked about the experimental room and their movements were translated to movements within the VE by means of a position and head-tracked HMD. In the 'visual turn' mode, users controlled locomotion by means of a joystick and in the 'real turn' mode turning was controlled by movement of the subjects' head, whilst forward movement was controlled by the computer. Their results of two experiments suggested that there '...was a difference in performance between the Walk and Visual Turn locomotion

modes, showing that vestibular and proprioceptive information contribute to the ability to perform ego centric updating.’ Once again the additional kinaesthetic and vestibular information aids spatial cognition within a virtual environment.

Finally, a paper by Templeman et al (1999) describes the use of a system which allows more naturalistic movements to be translated to locomotive movements within a VE. Naturalistic movements mimic more closely the movements used whilst navigating a real environment and therefore provide similar kinds of haptic and vestibular feedback. Other systems such as the omni-directional treadmill [see Darken, Cockayne & Carmein (1997)] and the ‘Virtual Perambulator’ [Iwata & Fujii (1996)] are discussed but the focus of the research is on the ‘Gaiter’ system. This system uses sensor-based controls, allowing the user to navigate in virtual space by ‘walking in place’ in real space. The Gaiter system allows virtual motion in any direction, unlike earlier unidirectional systems, and is also compatible with other actions such as jumping or crouching. Further issues relating to methods of virtual locomotion are discussed by Darken, Allard & Achille (1999). Debate is still active over the extent to which non-visual information aids navigation in space and research is still ongoing.

Field of view issues

The viewers’ visual field or field of view (FOV) is the visual angle subtended at the viewer’s eye [Psotka, Sonya & King (1998)] and differs between the observation of real worlds and that of virtual ones. In general the FOV in a real environment is larger than that simulated in a VE. The fields of view in immersive (HMD) and non-immersive (Desktop) systems, referred to as the geometric fields of view (FOVg) [the visual angle depicted in the virtual scene] often differ and are dependent on the optical

and graphical capabilities of the system. Different display devices may support different FOVg's which normally fall between 60 and 100 degrees, however manufacturers' estimates of the FOV of their systems has been suggested to often be inaccurate [Rinalducci, Mapes, Cinq-Mars & Higgins (1996)]. Changing the geometric FOV of a display (either a desktop or head mounted display) leads to visual distortion in the same way that changing the properties of a camera lens effects the visual scene. Smaller FOVg's lead to distortion much in the same way as looking through a magnifying glass and larger FOVg's result in the effect of looking through a fish-eye lens. Widening the FOV may allow more of the environment to be seen from one perspective and may increase feelings of presence [Hendrix & Barfield (1996)], but it has drawbacks such as increasing motion sickness [Pausch, Crea & Conway (1992)]. The result of a narrower horizontal field of view in virtual environments is that additional rotations of the viewpoint are needed in order to observe all 360° of the environment from one location. A human's natural FOV is approximately 180° horizontal and 120° vertical and therefore natural observation of the real world includes some peripheral information which may be absent whilst exploring virtual environments. Ruddle, Payne & Jones (1998) suggested that on occasion participants accidentally travel past important targets as a result of restricted FOV and peripheral vision.

A number of investigators have examined the effects of changing the field of view on spatial tasks carried out in virtual environments, however findings are not consistent. This could be due to an interaction effect between FOV and the characteristics of the task as well as the complexity of the task. Ruddle et al (1998) had participants navigate along simple paths in a virtual building under 2 levels of horizontal FOV (45 degrees and 90 degrees). They failed to find a significant effect of field of view. This

finding was in accordance with the study by Peruch, May & Wartenburg (1997) who examined the effects of three different FOV's on participants' ability to estimate the location of a previously visited location within a virtual space. Once again no effect was discovered. Contrary to these findings Alfano & Michel (1990) found a significant main effect of field of view when testing participants' knowledge of the spatial relations of objects in a room. An early study by Smith (1958) revealed an effect of FOV on estimates of distance. Larger FOV's led to distance being underestimated.

Waller (1999) carried out two experiments within a very simplified virtual environment, in the form of a dark grey cubic room containing a small red and green box. In the second experiment participants were exposed to a number of trials in which the geometric field of view and positions of the cubes were randomised. Three FOVg's were used and in each trial participants were asked to estimate the distance between the cubes. The statistical analysis found that a smaller FOVg resulted in longer times in the decision making process and a larger FOVg resulted in overestimations of distance, contrary to Smith's (1958) findings. Further perceptual affects of altering fields of view are discussed by Psotka et al. (1998) including affects on size estimations and self-location.

Previous experience

From the moment we are born, we learn to navigate the world and actively explore it. This continues throughout life and navigational skills may be better in some than in others, for example, those whose jobs may involve a need to navigate, such as taxi drivers, pizza delivery staff etc. Some people may also be better at using navigational aids, such as a map or compass, than others. Navigation and way finding are skills

that can therefore be learnt and built upon via extended life experience. However, people's experience of virtual navigation (moving through a simulated environment) is normally limited or absent. Extended navigation leads to familiarity with an environment which has been shown to affect spatial knowledge. Ruddle, Payne & Jones (1998) examined the effect of familiarity on participant's abilities to navigate two virtual buildings using a desk-top system. Spatial knowledge was assessed in their experiment (experiment 2) using measures of route-finding ability, sense of straight-line distance and direction estimates. The results suggested that spatial knowledge improved after having had prior navigational experience of the first virtual building. Route finding and sense of relative distance was more accurate in the second building and this could have been as a result of familiarity with the environment. It was also suggested that increased familiarity with virtual environments in general (e.g. learning to use the user-interface) might have led to more accurate spatial judgements.

Means of navigation

As mentioned above, the most common means of navigating our environment is by foot or motorised vehicle. When one learns to drive the initial focus is on the mechanics of movement and not necessarily on where one is going. Learning ones way about comes later once the mechanics of movement are second nature. This is an issue which has to be considered when navigating through virtual environments. The means of navigation is not naturalistic and has to be learnt. Translation of movement from the user to the computer is often by means of a keyboard or joystick (as discussed in Chapter 1). Other devices can be used such as a Spaceball, but the user needs to learn how to co-ordinate their movements in order to achieve the intended movement within the virtual space. Such abstract interfaces may slow down spatial

learning and so more naturalistic means of controlling movement are being researched (see above for discussion of ambulatory devices). Delays between movements of a tracked limb (e.g. the hand by means of a sensor glove) and the virtual limb may exist leading to confusion. Movements may be more constrained or slower within a VE due to the rate at which the visual scene can be allowed to change.

Visual fidelity & external cues

Virtual environments differ in their levels of complexity and visual detail. Colours and textures may not always match those that exist in real space. Many environments fail to include detailed features and if such details are present, they may only be observed when close to an object due to distancing and rendering problems. Simple environments may also be lacking in other visual cues and this in turn may reduce the number of available cues which can be relied upon as landmarks. In their third experiment Ruddle, Payne & Jones (1997) examined how local landmarks, that is to say ones that are within the navigable space, affected development of spatial knowledge in a virtual building. They exposed 2 groups of participants to the virtual building. However each group had a different arrangement of landmarks placed at key decision-making points in the building; Group 1 had landmarks at one end of the building and group 2 had them at the other end. When participants navigated parts of the building that contained the landmarks (everyday objects such as a car, clock, fork, house etc.) their route-finding skills were significantly better than when they navigated areas which contained no such internal cues. Route-finding, however, was not improved when more abstract landmarks (abstract paintings on cuboids) were used in their second experiment. It is difficult to determine to what extent landmarks and visual cues affect ability to navigate and way-find. Further work using landmarks

will be discussed in Chapter 4 and the experiments on distal and proximal cues, presented in that chapter, further investigate the differential effects of cues on a search task. In addition to visual cues, the real world may contain auditory cues that can be localised by an individual and used as an aid to navigation. Sounds in virtual environments cannot be easily localised and may not predict locations as easily and many virtual worlds lack auditory cues completely. Further research into how such non-visual cues are used is needed. The more 'realistic' a virtual environment is, the higher the cost of design and longer the time needed to create it. The use of texture mapping of surfaces etc. also requires additional computer processing capacity which may slow movement down within the simulated environment. Time, cost and technological constraints therefore often lead to virtual environments being representations of real ones, with some features of the original environment missing.

Levels of presence

Presence is a psychological concept which is used to express the degree to which someone navigating a virtual environment feels as if they are physically there within it. Steuer (1992) defined it as a feeling of "being there". Witmer & Singer (1994) defined it as the subjective experience of being in one place when one is physically in another. Although not a physical concept, attempts to measure levels of presence have been devised and can be seen to differ across different VR systems [Schuemie, van-der-Straaten, Krijn & van-der-Mast (2001)]. Measurement is often by means of a questionnaire such as those used by Singer, Witmer & Bailey (1994) or Hendrix & Barfield (1995). The highest level of presence occurs when navigating the real world and levels within virtual environments are determined by a number of factors. Immersive systems tend to increase feelings of presence compared to desk-top

systems, as do systems such as the CAVE [see Cruz-Neira, Sandin, Defanti, Kenyon & Hart (1993)]. Desk-top systems have been found to be no different from more immersive systems however in terms of learning spatial abilities [Gamberini (2000)].

The above discussion has focused on differences between real environments and virtual ones. It is clear that the two are not identical, however this is not to say that VEs cannot help us to understand spatial cognition. It should be noted though that cognition within VEs may also not be identical to that within a real three-dimensional world.

2.4.3.2 Large versus small-scale space

Psychologists have used a number of environments to examine spatial cognition ranging from models of places to actual real spaces such as office buildings. One topic of discussion within spatial psychology has focused on the mathematical concept of scale and researchers such as Weatherford (1985) have sub-divided space into categories dependent upon this element. Environments are often referred to as 'large-scale' or 'small-scale' but it isn't always clear what the distinction between these two categories is. Indeed Weatherford (1985) points out that some researchers may even refer to environments as large-scale when in fact they are simply large in size but do not strictly fit the criteria for being large-scale, as described below.

Weatherford (1982) makes a distinction between three different types of space. He categorises space into;

- 1. Model / small-scale space*
- 2. Small-scale / navigable space*
- 3. Large-scale / navigable space*

An example of a spatial task using a model is the classic three mountain task used in examining egocentric thinking by Piaget & Inhelder (1967). Spatial tasks of this nature do not allow the observer to navigate within the space and in a sense are map forms of what may be a real space. The other two classifications of space differ from the first, in that they are of a form suitable for navigation. An example of a small-scale space would be a single room with say furniture and objects placed around it. A three storey blocks of flats would be an example of a much larger or large-scale space. So what exactly are the defining properties of small and large-scale spaces? Model space (small-scale) is defined as space which cannot be observed or manipulated from within it, in other words it has to be viewed from an external point of view [Weatherford (1982)]. The major difference between small and large-scale spaces is related to how much spatial information can be observed from any one fixed vantage point within an environment. If a space can be viewed in its entirety from one such fixed position then it is small-scale by definition. On the other hand, if only a small section of the total space is viewable from one vantage point, then the space is, by definition, large-scale. The vantage point is generally referred to one which is in the same plane as the spatial layout [Weatherford (1982)] and is considered 'earthbound' according to Blaut & Stea (1974).

Large-scale space typically takes considerably more time to navigate and requires extensive exploration to integrate the visual information from multiple viewpoints into a representation of the entire space. Studies using large-scale environments may therefore require extra resources, both in terms of running them (i.e economic costs of running will be higher because of the extra time needed) and in terms of cognitive resources (cognitive demands are higher). Bearing this in mind, the experiments

presented in this work are all small-scale in design. The tray task described in Chapter 3 is more closely related to a small-scale model environment.

Large-scale environments may be represented as a physical map, often a plan-view or alternatively as a mental representation, commonly referred to as a cognitive map. Experiments involving large-scale environments have therefore focused on the construction and nature of this cognitive representation [Hazen, Lockman & Pick (1978), Anooshian & Young (1981), Feldman & Acredolo (1979)]. However, it was the work of Siegel and White (1975) [later also Pick & Lockman (1981)] who initiated research into the spatial cognition of larger-scale environments by suggesting that in order to operate within complex space levels of spatial knowledge must exist. They suggested a three level system of spatial knowledge development involving landmark knowledge, route knowledge and finally survey or configurational knowledge.

The first tier of the system involves noticing the presence of landmarks in an environment. Landmarks are salient places within a space [Anooshian (1988)], for example, the Centre Point building in London may be used to aid navigation for a tourist unfamiliar with the city. Landmarks may be local or may be more distant but visible from within the environment. Once landmarks have been isolated, motor sequences are developed which link a series of landmarks using routes. Such routes are sequences of stimulus-response behaviours (e.g. 'turn left at the church') linking a start position to a goal; these form the second tier of spatial knowledge acquisition. The final level involves relating the landmark and route knowledge into survey-map knowledge which is identical to the topography of the environment. It is only at this level that shortcuts and detours can be successfully employed.

A mental representation of space can be obtained directly by navigation of an environment or from a map. Maps are a popular way of representing small-scale spaces or of representing smaller sections of large-scale space. Studies carried out using small-scale environments have highlighted a phenomenon known as the 'alignment effect'. This can be observed when participants are asked to navigate an environment using a map. When the 'up' direction of the map does not correspond to the 'forward' direction in the actual environment then navigation is more prone to errors of judgement as are direction estimates. Roskos-Ewoldsen, McNamara, Shelton & Carr (1998) found orientation effects in both large- and small-scale spaces and Richardson, Montello & Hegarty (1999) also found evidence for alignment effects when learning from a map. However contrary to these findings, studies examining large-scale space have not always found evidence for alignment effects in spatial tasks and have been described as orientation independent [see Thorndyke & Hayes-Roth (1982), Presson, DeLange & Hazelrigg (1989)].

Investigations of possible alignment effects are based upon research into design principles which may be applied to map-based representations of space. For example, "...the *alignment principle* states that the map should be aligned with the terrain" and that "...a line between any two points in space should be parallel to the line between those two points on a map." [Darken & Sibert (1996) pp. 51]. Research by Darken & Sibert (1996) investigated navigation in a virtual large-scale space and called upon a number of design principles in order to try and aid navigation within this space. As navigation within large-scale virtual spaces is notoriously difficult, these researchers chose to investigate a number of techniques that could be used to aid the user in navigating and orienting successfully within a virtual environment.

The environments used by Darken & Sibert (1996) were *seascapes*. These are large areas of water containing randomly placed land masses (islands) and a number of targets. In their 1996 study, the researchers used a seascape with four distinctly shaped land masses and five ships as the target locations to remember and navigate towards. The islands had no topographic features such as mountains or valleys which could be used to help navigation. Navigation within the environment, using an immersive system, was not restricted in any way, although an invisible boundary prevented participants from straying too far afield. Four display conditions were investigated to determine their effects on navigational ability. These conditions were;

1. *A control condition with no navigational aids*
2. *The addition of a radial grid dividing the environment into sections*
3. *The addition of a YAH (You are here) map with a marker representing position and orientation*
4. *The addition of both a map and a grid*

Participants were required to make both *naïve* (uninformed) and *primed* (informed) searches to locate the targets. Darken & Sibert define a naïve search as one “...in which the navigator has no a priori knowledge of the whereabouts of the target” (pp. 54). Uninformed searches require an exhaustive search of the whole of the virtual environment. A primed search however is non-exhaustive and assumes that the navigator has had some previous information regarding the position of the target. Analysis of the results revealed no consistent effect of different display condition, with some measures showing a main effect for display condition (map direction error, ratio of area to search time) and some not (map distance error, naïve search time). General trends in the data suggested that the map conditions were superior to the control and grid conditions, but that the grid was better at improving directional

estimates. Analysis of actual search strategies highlighted four main methods used by the participants. These were;

1. *Edge strategy: Participant follows the edge of the land masses (most common strategy)*
2. *Lawnmower strategy: Participant makes parallel movements up and down the world or from left to right.*
3. *Area strategy: World split into segments and searched area by area*
4. *Heuristic strategy: Search focused in specific area*

Similar strategies have been observed by Ruddle, Payne & Jones (1999a) who also investigated the effects of maps on navigation in large-scale VEs. They further examine the benefits of maps and other aids (compass device) on ability to form mental representations and focus on different types of mapping device (global maps versus local maps). The findings of a previous study by the same authors [Ruddle, Payne & Jones (1998)] suggested that a compass gave little help in terms of navigating a virtual building (there was no main effect of compass display for any of the measures used) and concluded that although participants may have altered their strategies, effective navigation with a compass may need initial training. The same finding was found in their 1999 study, where in fact the compass display condition actually led to worse performance than a control (no aids) group. They again concluded that "...a compass or other similar aids...are not suitable for the navigation of very-large-scale VEs unless people are trained to effectively use them." [Ruddle et al (1999a) pp. 73].

With respect to different types of mapping, Ruddle et al (1999a) discovered that navigation in very large-scale virtual environments (seascapes again) was enhanced by a combination of both a local *and* a global map. The scale of a map may effect the

users' ability to transfer the knowledge to the actual terrain. Their study used a non-immersive desktop system to expose participants to virtual seascapes under five display conditions. These were;

1. *No visual aids*
2. *A global map*
3. *A local map*
4. *Both a global and a local map*
5. *Co-ordinate system with a compass*

The map aids were all North-up 'You-Are-Here' type maps, once again adhering to general map design principles and also considering the concepts of pictorial realism, visual momentum and optimum scaling. A global map uses a small scale to present the observer with a representation of the whole environment using a single view. Local maps however use a larger scale to show areas of an environment in greater detail, allowing objects and features to be seen and distinguished that would not be visible on a global map. Ruddle et al (1999a) discuss the advantages and disadvantages of these two different types of visual aid in their paper. Despite the additional cognitive demands of the dual map condition (global & local maps available to the user at the same times) the results showed that this combination was overall the best navigational aid; however after a suitable period of time those participants in just the global map condition performed as effectively. Ruddle et al (1999a) suggest that the slower performance of those participants exposed to just a local map is a result of having to integrate numerous ego-referenced positions. Performance was measured using straight-line distance estimations and position estimates (using a plan view test and distance travelled (percentage extra distance was used)).

This problem of viewpoint integration brings us back to the initial issue of the differences between large and small scale environments. Large virtual environments such as those used in the navigational studies described above may lead to disorientation due to the difficulty of integrating views from multiple points of reference into a cognitive representation of the whole environment. Visual aids have been shown to help, however spatial tasks that use *small scale* environments may help to lower cognitive demands. Small scale virtual environments, especially ‘cluttered’ ones, may however still sometimes lead to disorientation, dependent on field of view and other environment factors [see Ruddell & Jones (2001)]. The environments that form the basis for the studies reported in this thesis are therefore small scale and can be considered as ‘search’ type tasks as opposed to navigational ones.

2.4.3.3 Training in virtual environments & transfer of training

Years before virtual reality fell into the hands of academic institutions, simulated environments were being used by the military to train skills required by pilots. Such simulations are useful when “...it is not possible, practical or safe to use the actual physical location to train.” [Witmer, Bailey, Knerr & Parsons (1996), p. 414]. Two key issues which are currently being researched by psychologists and computing specialists are whether or not skills can be learnt within a virtual environment and whether such skills can be transferred to real-world situations. Regian, Shebilske & Monk (1992) suggested that “Virtual reality may hold promise for simulation-based training because the interface preserves (a) visual spatial characteristics of the simulated world, and (b) the linkage between motor actions of the student and resulting effects in the simulated world.” (p. 136). They also pointed out that prior to the initial research carried out in their paper, there had been no empirical studies

which examined skill training and transfer of skills learnt in a virtual environment to the equivalent real-world task. Durlach, Allen, Darken, Garnett, Loomis, Templeman & von Wiegand (2001) discuss why virtual environments are suitable for training purposes. They mention the cost-benefits, the reconfigurability of VEs, the possibilities of providing “magical” navigation aids and the potential to provide virtual training partners.

Regian et al (1992) examined how VR environments can be used to train both procedural and navigational tasks. Procedural tasks are ones which involve a sequence of events which can be performed within a small-scale environment. Kreuger (1991) highlighted VR as being an ideal interface for the training of such tasks, especially when the environment allows learning to occur within a meaningful context. Navigational tasks generally involve larger-scale space and require navigational experience to build configurational knowledge, which is then stored as a cognitive representation of the environment [see Regian (1986) cited in Regian et al (1992)]. Their experiments used two virtual environments, one small scale, known as the virtual console and one large-scale, referred to as a virtual maze. The virtual console was constructed as a three panel display, each panel with a number of knobs, buttons and lights. Participants were trained to learn a complex sequence of 17 steps under conditions of ‘meaningful’ (verbal comments about what each button / knob does) and ‘non-meaningful’ context. During the testing phase participants were required to repeat the procedure taught during the training phase. The results indicated that all participants were able to repeat the procedure after initial training, that a learning effect was present and that there was no effect of learning context.

The virtual maze was a building constructed of 3 floors with 4 rooms on each. Each room was identical in structure and colour but could be distinguished by a unique

coloured object which was present. A combination of 4 object shapes and 3 colours were used. Each room was linked to another by connecting hallways allowing navigation from room to room and floor to floor. The number of connecting hallways was balanced throughout the whole building. Participants were trained to navigate the building using both guided tours and free-exploration and then tested in a test phase involving navigating from a start room to a goal room. Performance was compared to a Monte-Carlo simulation and the results on the whole indicated that configurational knowledge could be learnt in the training phase. This experiment also showed that spatial knowledge could be learnt even in impoverished simulations which lack the usual spatial and geometric cues (e.g. cues such as doors, windows, paintings, furniture etc.) present in many virtual and real environments. A similar finding was reported by Bliss, Tidwell & Guest (1997) in their fire-fighter study (see further detail below), which used a virtual environment that lacked many visual features present in a real building. In fact some studies [see Lintern, Roscoe & Sivier (1990)] have shown that reduced fidelity of the virtual scene may actually aid learning. [See also Waller, Hunt & Knapp (1998) discussed later below for research into fidelity effects on training transfer]. When Regian et al (1992) repeated the maze experiment using a two-dimensional map-like representation of the building, performance was found to be worse than for the three-dimensional virtual reality version, indicating the additional benefits of more 'real' representations of space.

This initial study into VR training prompted further research examining training and transfer of training in virtual environments. Research includes that carried out by Witmer, Bailey, Knerr & Parsons (1996), Bliss, Tidwell & Guest (1997), Tate, Sibert & King (1997), Waller, Hunt & Knapp (1998), Koh, von Wiegand, Garnett, Durlach & Shinn-Cunningham (1999), Banerjee, Banerjee, Ye & Dech (1999), Rose, Attree,

Brooks, Parslow, Penn & Ambihapahan (2000), and Durlach, Allen, Darken, Garnett, Loomis, Templeman & von Wiegand (2001).

Witmer et al (1996) examined three groups of participants trained to follow a complex route within a large-scale office building. The three groups consisted of male and female participants who had rehearsed a route by means of a virtual simulation of the actual building (VE rehearsal), symbolic training materials (symbolic rehearsal) or navigation of the real building (building rehearsal). The symbolic training materials consisted of written routes and colour photographs indicating landmarks and destinations. The VE rehearsal group was exposed to a very high fidelity computer simulation of the actual building by means of an immersive set-up (BOOM system used). After training, the VE rehearsal group was given presence and simulator sickness questionnaires to complete. All three groups were then assessed on the learnt routes within the real office building using a route knowledge test that measured wrong turns, distance travelled and route traversal time. Results concluded that route learning occurred during training under all three training groups, however performance was best for the 'building rehearsal' group, followed by the 'symbolic rehearsal' group and finally the VE trained group. When transfer of training was examined, it was concluded that actual navigation of the building led to the highest performance during transfer tests, followed by VR training and lowest performance for the 'symbolic' trained group. These results are indicative of positive transfer of route knowledge from a virtual to a real environment, although it was discovered that configurational knowledge was not affected by the training medium. Witmer et al (1996) finish by discussing the potential applications of virtual environments to training and briefly touch upon the possibilities of training emergency personnel in entry and rescue procedures.

The training of emergency staff was empirically studied by Bliss, Tidwell & Guest (1997) the following year. They focused on the effectiveness of virtual reality for administering spatial navigation training to fire fighters in a previously unfamiliar building (Administrative Sciences Building (ASB) at the University of Alabama). The ability to navigate unfamiliar territory is one which all fire fighters need to do, in order to perform entry and rescue operations. Such navigational tasks are also made more difficult by the presence of smoke, fire and often a lack of artificial lighting. This may result in fire staff having to follow routes by means of sticking closely to a wall and almost feeling their way about. Training of fire personnel may occur in real buildings which are set alight for the purposes of training staff, however this is costly and has obvious dangers associated with it. Training via a safer and more economic medium is therefore beneficial and this is where VEs can be used. Bliss et al's (1997) study chose to train fire-fighters to learn a rescue route through the third floor of a building using three different methods. One group were trained using two-dimensional blueprints of the building, another using a VR simulation and the third group acted as a control, and were given no initial training at all. The 'blueprint' group were trained to draw a route in pencil on an overhead plan of the building, whilst the VR group were exposed to a virtual model of the actual building using a fully immersive head-tracked Onyx (Silicon Graphics) system. Navigation was controlled by a standard three-button mouse which controlled forward and backwards movement, and direction of movement was always in the direction of the viewpoint (controlled by head movements). After the training phase, the two trained groups were taken to the actual ASB and asked to rescue a victim by following the previously learned route. The untrained group were also asked to search the building but using the standard methods for 'search & rescue' in unfamiliar environments. To help

mimic the reduction of visual detail due to smoke and absence of light, all three groups were required to wear goggles which were sprayed white, a common method used in training fire fighters. Time to follow the route and number of incorrect turns required to rescue a doll (the victim) were measured. The results suggested that participants who received either VR training or blueprint training made less errors and navigated faster than the group who had been given no initial training. The VR trained group did not however perform any differently from the blueprint trained group and this may have been as a result of increased familiarity with the blueprint method compared to virtual reality environments. Despite the lack of a significant difference between the two training conditions, the findings of this study still support the transfer of route knowledge from a computer simulation to the actual environment.

A similar study was performed by Tate, Sibert & King (1997) who trained naval fire-fighters using a VR rehearsal method. Movement was this time also controlled by a 'glove avatar' and a joystick. The virtual environment was a simulation of an actual testing vessel used to train for accidents aboard ships and under some conditions included simulation of fire and smoke. Performance was found to be improved when traditional training was enhanced by rehearsal using the virtual environment and fewer errors were made by groups trained using VR.

Waller, Hunt & Knapp (1998) report the findings of a study used to investigate the factors which mediate transfer from virtual to real. They focused on the issue touched upon earlier of fidelity, which can be defined as "...the extent to which the VE and interactions with it are indistinguishable from the participant's observations of and interactions with a real environment." (p. 130). Fidelity can include similarities of the visual content of the virtual environment and that of the real one. Presence or absence of visual cues (objects that can be used as landmarks), matching colours and textures

are examples of visual features which may in turn affect transfer of training. Other elements include the similarity of aural cues, kinaesthetic cues and the degree of similarity between movements and actions in the real and the virtual one. Waller et al (1998) highlight three information domains involved in transfer of training. These are information stored in the virtual environment, information stored in the mental representation of the virtual environment and thirdly, information stored in the real environment. They define fidelity as being concerned with the quality of mapping from one domain to the other and suggest that each is mediated by environmental fidelity or interface fidelity. Environmental fidelity affects the mapping from the real world environment to the training environment, whilst interface fidelity affects maps from the virtual environment to the mental representation of it. In the study carried out by Waller et al (1998), they manipulated both these factors to determine the effect on transfer of training.

Participants were presented with a 14 by 18 feet maze which contained 4 stuffed toys acting as landmarks. A virtual version of this maze was also constructed using the SENSE8 WorldUp software package. Participants were split across 6 exposure conditions as follows;

1. *Blind – no pre-training*
2. *Real maze training*
3. *Map training*
4. *Virtual Reality Training using desk-top immersion*
5. *Short Virtual Reality Training using full HMD immersion (2 min exposure)*
6. *Long Virtual Reality Training using full HMD immersion (5 min exposure)*

Subjects were tested on the real maze by means of a 'blindfold task' which involved them being blindfolded and asked to navigate, as quickly as possible, to touch each of

the stuffed toys in a given order. After six blindfold task trials, part of the maze was changed and participants were asked to move directly from the first stuffed toy to the third. This involved having to rely on the mental representation of the maze to determine alternate routes to take and was termed an 'integration' task. Finally, a 'true-false' task was used in which partial maps of the maze had to be identified as correctly or incorrectly representing a section of the real maze. The results suggested that all forms of training improved performance in the real maze, but that VE exposure time may affect the performance. Short VE exposure led to no differences between the short VE group and the map group, however when exposure was increased performance was equivalent to real-world training and better than map training. The 'true-false' test highlighted better performance for the map group and an effect of gender (males slightly outperforming females). The authors concluded that environmental and interface fidelity has little effect on route knowledge acquisition. This study provides an explanation for why transfer of training can occur using virtual environments which have low fidelity, such as that used by Regian et al (1992).

Koh, von Wiegand, Garnett, Durlach & Shinn-Cunningham (1999) used a number of training techniques to examine transfer to a section of the seventh floor of building 36 at the Massachusetts Institute of Technology. Unlike many of the previous studies, this experiment looked at the learning and transfer of configurational knowledge as opposed to route knowledge. This was done by asking participants in the real environment to make directional estimates (bearing and range measured) to one of five landmarks from one of four station positions. In the real-world tasks, people were taken from one station to the next by means of a wheelchair whilst blindfolded and then asked to make their estimates. Prior to the testing in the real world, participants were trained either in the real environment, in a virtual reality environment

(immersive or desktop), or using a computer model (which had the ceiling removed). The findings of this experiment showed no significant differences between different training methods including the different VR conditions (immersive versus non-immersive). Training by the use of VR environments was as affective as training in the real-world. The authors also observed a consistent bias in bearing estimates, in that participants generally underestimated the direction of the target. They suggested that "...subjects thought that the rectangular space was wider than it actually was..." and that they therefore "...tended to "square the rectangle"" (p. 653). However comparisons to previous studies cannot really be made, as most of the previous work has concentrated on route knowledge, whereas this study measured configurational knowledge.

Banerjee, Banerjee, Ye & Dech (1999) trained participants to carry out a highly complex object assembly procedure using virtual reality. They compared both desktop and immersive (CAVE system) systems with the standard blueprint technique for assembling complex mechanical parts. In the training and practice session of the study, participants were asked to generate an assembly sequence for a given object (an 11 part gear pump). Questions could be asked of the experimenter and the sequence was corrected accordingly until it was the best one for the task. In the experimental session participants were again asked to construct an assembly sequence (for a 34 part air cylinder) but were not given any feedback. All three groups were then asked to describe the assembly process in words and the VR groups were also asked to then assemble the object. After the experimental session, participants were given a questionnaire to fill in which rated various aspects of the task (quality measures) were questioned. The general findings of the study were that using the virtual environments

was advantageous to the traditional blueprint approach. However few differences in performance were observed between the immersive and the desktop VR groups.

Rose, Attree, Brooks, Parslow, Penn & Ambihapahan (2000) used a simple sensori-motor task to determine what exactly is being transferred from virtual to real environments. Previous studies have certainly shown positive transfer from virtual to real but few have focused on the nature of the actual elements being transferred. For example, increased performance in the real world, after initial training within a virtual environment, may be a result of increased familiarity with a given task or with the environment the task is performed in. Rose et al suggest that equivalent performance in real and virtual environments may not always be the case and that additional scrutinization may highlight differences. Their three experiments looked at performance on a 'steadiness tester', the type of apparatus sometimes seen at fairs, in which a metal loop (diameter of 8 cm) has to be moved over a convoluted wire without touching the wire itself. The metal loop is connected to a handle which is the same shape as a 3D mouse used to perform the virtual version of the task. The aim of the task was to move the metal loop from one end of the wire to the other without contacting the wire, using the non-dominant hand. A virtual version of the task was also used in which the virtual metal loop was controlled by a 3D mouse (a tracked hand-held device). This virtual task was presented via an immersive headset (the dVISOR HMD). An error was recorded every time the participants touched the wire with the ring (or the virtual wire with the virtual ring in the VR version) and this was highlighted to participants by a change in colour of the background (a Perspex screen was used in the real-world task which glowed when an error was made).

The first experiment investigated performance on this task after real world, VR and no training conditions. Participants in the two training groups were trained on 8 trials,

whilst the non-trained group were simply asked to navigate an unrelated virtual environment for 15 minutes. Post-training, groups were tested on the real sensorimotor task and mean errors were compared. The results confirmed that the group which had received no prior training in either the real-world or the virtual environment made significantly more errors on the post-training test trials. The two trained groups made less errors and there was no difference between these two groups on the test trials. This suggests that the real and virtual training are equally effective, however Rose et al (2000) make a point that this "...does not assume equivalence between what is learned in virtual and real task training" (p. 500) and that one form of training may require higher cognitive demands than the other.

Their second experiment investigated these cognitive loads by introducing concurrent tasks which have been shown to interfere with performance on similar tasks. It was hypothesised that if the cognitive load of the virtual training were different from real-world training, introduction of additional tasks would differentially affect performance on post-training trials. Two groups of participants were assigned to conditions of 'motor interference' or 'cognitive interference'. The two groups were given an additional test trial (in addition to the procedure followed in experiment 1), post-training, and asked to carry out an extra task whilst completing the sensori-motor task. The 'motor' group were required to tap on a key in time with an audible beat, and the 'cognitive' group were read a list of words and asked to say "yes" when fruit names were identified. These extra tasks were performed concurrently with the steadiness tester task. Errors were once again recorded and the findings showed that the 'motor interference' negatively affects performance on the additional test trial more than 'cognitive interference' does. No interaction of previous training type by interference condition was observed, however it was observed that interference has a smaller effect

on performance of the previously VR trained participants compared to those who were trained using the real-world task. This suggests to some extent that VR trained tasks become automated more easily than real-world trained ones, and are therefore less sensitive to interference effects.

Their final experiment in this series followed up the findings of the previous experiment by investigating participants' abilities to respond to irrelevant stimuli and instructions whilst carrying out the real-world sensori-motor task. Rose et al (2000) suggested that the groups who had been pre-trained using a VR environment should have additional attentional resources available to them compared with those who were given real-world training, and that this should result in increased ability to attend to irrelevant stimuli materials. After an initial real-world performance trial, participants were trained either in VR or the real world. During a post-training test trial (Real world) the two groups were exposed to both visual stimuli (colours on a computer screen) and auditory stimuli (tones played). After the post-training trial, subjects were asked to identify which visual stimuli were presented previously by ticking them on a sheet that listed additional distractors in addition to the targets. For the auditory stimuli, participants were simply asked to estimate the total number of *different* tones that they had heard. Results once again demonstrated equivalent performance of the two training groups (as in experiment 1), however, contrary to the hypothesis, no differences were obtained on measures of attention to auditory or visual stimuli materials. This finding is interpreted in light of the idea that cognitive demands of real world and VR tasks are *both* high enough to restrict attention to irrelevant stimuli. In addition to backing up research on transfer of training, this study highlights possible cognitive demand differences between real and virtual training, and in fact suggests

that VR training may be beneficial, especially for those people who have diminished cognitive capacity.

All of the above studies trained skills in adult samples, however, a study by McComas, Pivik & LaFlamme (1998) investigated transfer of spatial learning in 6, 7 and 8 year old children. The children were either trained in a real classroom setting or used a desktop virtual simulation. The real classroom consisted of a room cleared of furniture but still contained landmark cues such as blackboards, windows etc. Within the classroom was a circle of equally spaced cardboard clowns, each holding a bag containing a piece of a wooden puzzle. To complete the puzzle, the children had to visit each of the clowns to collect the 10 puzzle pieces; this was considered to be one trial. This task is analogous to animals visiting separate arms in a radial maze to collect food pellets. The VR version of this task was built using the Quake compiler software and included texture mapped clowns which were identical to the real-world ones. In both the real and VR tasks, performance was measured as a 'total percentage correct' and 'visit of first error' (the trial number where the first error occurred). Children were randomly assigned to either the VR trained or the classroom trained group and were told to collect all 10 pieces of the puzzle by visiting each of the clowns once. After collecting a puzzle piece each child was asked to return to the centre of the room to place the piece in a bag and then to close their eyes and rotate slightly. The rotation was performed automatically in the VR version and was used to help minimise successive adjacent choices or algorithmic strategies. Children in both groups were given 3 learning trials (in either the VR or the real classroom) followed by a final real-world test trial.

The results showed that for the initial learning trial, the real classroom group performed significantly better than the VR group, however by trial 4 this difference

between groups had vanished. When the first trial data was compared with the fourth (test trial) no difference between the two training groups was seen in terms of 'total % correct', however the results indicated that those children who had been given VR training made errors later in a trial than those who had real-world training. These results once again support the general findings of the adult studies presented earlier, in that participants trained using VR environments can perform equally well as those who have had real-world training.

Although it is clear that virtual reality can be used to train procedural and spatial skills, what is still unclear is what should be trained and how it should be trained. Many studies have focused on training specific abilities using specific virtual environments and less work has looked at training general spatial skills. Durlach et al (2001) suggest that there are still many elements that need to be taken into consideration when using VR as a training medium. They point out that there is a wide range of applications from which to choose and that having chosen a specific task or skill, there may be an infinite number of virtual environments that one can investigate. Many training studies which find differences across groups may be invalid due to the inherent variability of individual spatial skills and so the importance of measuring spatial skills prior to training is highlighted. Finding no significant differences between groups is therefore often more important than finding differences. Durlach et al (2001) propose a number of features which they believe are desirable elements of a VE training system. They suggest that a system with high fidelity is beneficial, but at the same time they point out that 'supernormal' features, such as transparent objects, may also be of use in some training scenarios. Optimising realism is not always the goal of researchers studying VR training. They also propose that systems should be flexible in that they should include various spatial tasks such as

landmark recognition, route following and configurational knowledge tasks and that they should allow for fast construction of environments. Finally they recommend that training systems should include programs that assess individuals' basic spatial skills and abilities, as a means of controlling for inter-subject differences. Further research into training of skills using VR needs to consider and adopt some of these principles.

2.4.3.4. Individual differences in spatial abilities: factors affecting performance in virtual environments

A number of factors can affect performance in virtual environments including task characteristics, environment characteristics, user characteristics and system characteristics [see Bowman, Davis, Hodges & Badre (1999), also Bowman, Koller & Hodges (1998)]. User characteristics lead to individual differences and, as previously mentioned, spatial abilities vary widely amongst individuals. Waller (2000) has investigated some of these differences using numerous tests of spatial abilities including, pencil and paper tests, real world tests and tests using virtual environments. His study examined a number of factors that have been proposed to affect an individuals' ability to acquire spatial information from a virtual environment. These include verbal ability, spatial ability, computer experience, gender, interface proficiency and real-world environmental knowledge.

The experiment was conducted in two sessions held within a month of each other. In the first session, participants were given a number of psychometric tests assessing visualisation skills, verbal ability, vocabulary and spatial orientation [Guildford & Zimmerman (1981) test battery, cited in Waller (2000)]. Questionnaires were also completed, which measured attitudes towards computers and previous computing experience, as well as spatial knowledge of the real space being tested [University of

Washington campus]. The second session began with real world estimates of distance and location of targets around the campus. Estimates of 3 targets were made from three separate sighting locations across the campus. Participants were then given a 'walkabout' task. This was a computer simulation of a route through a virtual environment. Participants are asked to make direction judgements within the environment and also asked to identify the building from a birds-eye view. After this, the participants were given time to explore a virtual maze and then to make distance and directional estimates in a similar way to the estimates made in the real-world task. Finally, subjects were taken to a real version of the VR maze they had just navigated and also asked to make distance and direction estimates to the same targets but from different locations. They were also asked to represent the maze on an overhead grid map using cardboard pieces to represent key locations.

The results were analysed and correlational methods were used to construct a latent variable model which represented the relationships between factors and variables of interest. Verbal intelligence measures were not found to be associated with measures of virtual environment spatial knowledge as had been expected, and significant correlations between .28 and .40 were obtained between spatial ability and VE spatial learning. These values represent a considerable source of variation due to individual differences in spatial ability. One of the largest factors which contributed to these differences was the individual's proficiency with the navigational interface. This suggests that prior training with the interface would be beneficial in reducing variance and helping to minimise individual differences. Waller (2000) suggests that the gender differences which were observed (men performing slightly better than women for VE spatial knowledge) were mainly due to females being less proficient with the interface than the males. Although gender may be a predictive factor determining

spatial knowledge acquisition in a virtual world, there are other influential factors which may account for gender effects. With respect to prior computer use and attitudes towards computers, Waller found only a minor contribution to performance in the virtual maze. One unexpected finding arising from this study was no significant association found between real-world spatial knowledge and knowledge of the virtual environment. Waller (2000) proposes that this may have been because the real world environment was familiar to the participants, whereas the virtual space was a novel, unfamiliar one. Finally, it was highlighted that the model constructed does not explain a large proportion of the total variance, and therefore further factors need to be examined to determine what causes individual differences in virtual environments.

A number of experiments carried out by Cutmore, Hine, Maberly, Langford & Hawgood (2000) also investigated some of the factors which influence navigation of virtual environments. Their five experiments examined the contributions of gender, cognitive style, active-passive navigation, hemispheric activation and display information on both route and configurational knowledge formed within a virtual space.

The first experiment examined whether active and passive navigation affects ability to navigate through a virtual maze environment. Active navigation involves actively making decisions about where to move, whereas with passive navigation the movement path is not controlled by the observer. Peruch, Vercher & Guathier (1995) also examined active-passive differences in virtual environments and found that wayfinding performance was best in those who were actively engaged in navigation, rather than passive observers. Other studies, for example Wilson, Foreman, Gillett & Stanton (1997), have failed to identify active-passive differences; also the Kiel Maze experiment (presented in Chapter 5) did not identify any difference in abilities

between locomotor (active) and non-locomotor (passive) groups. Gaunet, Vidal, Kemeny & Berthoz (2001) found no difference between active and passive exploration of a virtual city, in terms of scene recognition and direction estimation. Cutmore et al (2000) had participants move through a number of interconnected rooms (a maze structure) in order to find the exit. No landmark cues were included in the maze for the first experiment. Navigation was either active or passive (by observation of the moves made by an active participant) during the training phase and this was followed-up by a single test trial (active navigation). Their results suggested that navigational knowledge could be learnt from both active and passive navigation of a virtual maze and that there were no significant differences on performance in test trials across active-passive training groups.

Their second experiment included either landmark cues (1 cue associated with each room in the maze), compass directions or no additional cues (control [same as first experiment]) in the maze. After six training trials, participants in the three display conditions were tested by being asked to draw the quickest route through the maze on a 7 x 7 grid. The results suggested that local landmarks were more useful than compass directions in finding the location of the exit to the maze, with males using less trials than females.

Experiment three looked at a female sample only, to determine whether spatial ability as measured using standard tests, affects route and survey knowledge in a virtual passageway. The maze was the similar to that used in experiment two (including local landmarks), but with no choice-decision points. Distance estimates (straight line distance) between landmarks were estimated by participants who had traversed the passage way over 2, 4, 8 or 16 trials as well as estimates of the passage length. The results, analysed using a median split, showed that both route and survey knowledge

increased with increased exposure to the maze and that those people with better visual-spatial ability (as measured by WAIS-R block design scores) score higher on measures of survey knowledge. This finding is in accordance with Waller's (2000) findings, which outlined the importance of measures of general spatial ability on performance in virtual environments.

The forth experiment measured cognitive style of participants using a technique devised by Naglieri & Das (1987) [cited in Cutmore (2000)]. Two VEs were constructed, one which provided visual flow information and one which did not. Participants were trained on 4 trials in one of the two VEs and then tested on ability to navigate from the start point of the maze to the exit. Results showed that the participant's cognitive style affected ability to navigate and that this interacted with visual flow information. Cutmore et al (2000) suggest that representations of space may be different according to an individual's cognitive style.

Their final experiment measured brain activity whilst navigating the maze, using an EEG. Eight trials of the maze were presented to participants which were followed up with tests of distance estimation and navigation. The results confirmed that the right hemisphere is more activated during navigation than the left and that participants with low measures of visual-spatial ability have increased right hemisphere asymmetry, therefore show greater cognitive effort whilst navigating.

A further study investigated sex differences in performance on a virtual maze. Moffat, Hampson & Hatzipantelis (1998) measured verbal and spatial ability using standardised psychometric tests. After completing questionnaires about handedness and previous computer game experience, participants were exposed to five trials of two computer generated mazes. Their aim was to navigate the maze until they found the exit, marked by a door. Time to complete each trial was recorded as were route

errors (information errors & spatial memory errors). The analysis of the results supported previous research findings that males outperform females, on measures of completion time and error scores, even after a covariate analysis was undertaken [scores on computer game experience used as covariate]. Analysis of the data from the psychometric tests also confirmed higher scores for males on all tests of spatial ability and no difference between the verbal ability measures in terms of gender. Finally, correlations between the maze scores and psychometric scores were found to be mostly significant, however some of the correlations suggested that there are some differences between which factors of spatial ability are being measured by the tests.

These studies show that spatial abilities in virtual environments, as well as in real ones, are under the influence of individual differences. Interactions between such differences and the navigation interface may also lead to differences in spatial abilities as measured using virtual testing paradigms. It is these factors, and no doubt other factors, which help to explain the sometimes large variance in individuals' scores on measures of spatial ability.

2.5 Summary

To summarise, VR clearly has a great deal to contribute to the psychological domain. Despite one or two problems, such as cost, clinical acceptance and possible side-effects of immersion, the advantages of using VR in psychology very much outweigh the disadvantages. Rizzo et al (1997) list the main advantages of VR that are reiterated throughout the literature. These are as follows;

P.T.O

- VR allows the presentation of ecologically valid testing and training scenarios and/or cognitive challenges which are difficult to present using other means.
- Total control and consistency of stimulus delivery can be maintained with VR environments, focusing the users' attention where the experimenter wants it to be. VR helps to eliminate extraneous variables.
- Hierarchical and repetitive stimulus challenges can be presented, which can be varied from simple to complex, depending upon success and ability.
- Virtual testing environments can include "cueing" stimuli that are designed to help guide successful performance.
- Environments can be modified to take into account response requirements based on the user's impairments.
- Immediate performance feedback in various forms can be given to users and training can be paused for extra instruction or discussion.
- VR offers the capacity for complete performance recording and the option for self guided exploration when appropriate.
- Safe learning environments that minimise risks due to errors can be implemented.
- Gaming factors can be included in the test situation that may enhance motivation, particularly with children.
- VR allows the creation of economical functional training environments.

[based on: Rizzo, Buckwalter & Neumann (1997)].

Such an extensive list of advantages demands that VR research in psychology is further explored and the following chapters aim to show how virtual reality

technology can be used to implement and further our understanding of spatial cognition in humans.

In conclusion, Riva (1998) states that “Virtual reality software and hardware...are trends that could contribute to a richer understanding of the brain and enable sharing and exploration of conceptual models in ways never possible before.” (p. 191).

CHAPTER 3

VR assessment of neurological damage

This was a multi-part experiment, which consisted of three sections. The 3 sub-experiments described in this chapter are:

1. *The virtual golf course task*
2. *Assessment of spatial ability using the Benton's line test*
3. *The virtual tray of objects task*

3.1 General Introduction

The experiments described in this chapter were carried out with two groups of clinical patients; those suffering from Parkinson's disease and those who had received brain damage following closed head injury.

Parkinson's Disease (PD) is a progressive degenerative neuronal disease that effects approximately 120,000 British people and 1.5 million Americans, most of whom are over the age of 55. According to Stern & Lees (1982), an individual aged between 60 and 80 has a 1 in 100 chance of developing Parkinson's disease (residents of Northern Europe or the United States). Prevalence increases with age according to Mutch, Dingwall-Fordyce, Downie, Paterson & Roy (1986), cited in Caird (1991). Interestingly, non-smokers are twice as likely to develop PD than smokers. It is not suggested that nicotine itself is acting as an anti-Parkinson's drug here, rather that certain patterns of behaviour seen in non-smokers are associated with possible onset of PD.

The exact causes of PD are as yet still being researched, but its physiology has been well documented. The disease is caused by deterioration of very specific nerve cells found in an area of the brain known as the basal ganglia/striatal motor system (see Jellinger (1990)). The basal ganglia consist of sub-cortical nuclei (grey matter) located within the centre of the brain and form part of the control centres for voluntary movement.

Cells in the substantia nigra region of the striatal motor system deteriorate in PD and have been shown to often contain particles known as Lewy bodies, which form a concentric mass with a dark core and a pale halo. The neurones of the striatal system are dopaminergic in function, meaning that they use the neurotransmitter dopamine to bridge the synaptic cleft between pre- and post-synaptic neurones. Dopamine is produced by these cells in a process involving the conversion of tyrosine (an amino acid) into L-dopa (a precursor) and then into dopamine. In Parkinson's disease, this dopaminergic system is disturbed leading to a general dopamine deficiency.

A deficiency of dopamine in the nigro-striatal pathways of the basal ganglia region of the brain may in turn effect neural circuits in the frontal cortical-basal ganglia which have been theorised to effect executive skills [Bondi, Kaszniak, Bayles, & Vance (1993).]

Cruscian, Barrett, Schwartz, Bowers, Triggs, Friedman & Heilman (2000) looked at vestibulo-proprioceptive components of PD by administering the Water Jar Test whilst manipulating vestibulo-proprioceptive input (using a head tilt method). Their results suggested that manipulating vestibular input did not effect performance of the PD patients and that the patterns of errors that were made were suggestive of frontal lobe dysfunction. The extent to which dopamine deficiency in the nigro-striatal

pathway effects other brain regions is as yet not fully understood. For a more detailed description of the pathophysiology of PD, see Stern & Lees (1982).

Patients who suffer from PD show a number of problems, which have been categorised into primary and secondary problems. The primary symptoms are;

1. *Bradykinesia*
2. *Rigidity*
3. *Tremor*
4. *Problems with balance*
5. *Difficulties with walking*

Bradykinesia is the term used to describe the slowness and poverty of purposeful movement and is seen, for example, in a patient who finds it difficult to dress him/herself. Rigidity is an increased muscle tone; present when the patient is still, and which often increases when the person is moving. It can be recognised by the increased resistance of a limb to passive movement by an examiner / doctor. The third symptom of tremor is another characteristic displayed in up to 75% of PD patients. It is the involuntary shaking of parts of the body (normally hands, legs or head) and is rhythmical with small amplitude. It is probably the most visual of all the symptoms to a lay-observer. Patients may also have problems with balance, finding it difficult to maintain an equilibrium and failing to compensate adequately for sudden changes in position, leading to more falls and fall-related injuries. Finally, difficulties with walking are noticed, such as the shuffling gait that many sufferers exhibit. Stopping and starting walking is often a problem and the phenomenon of “freezing” suddenly (kinesia paradoxa) is sometimes observed. An approach to treatment of this “freezing” behaviour was developed by Riess and Weghorst (1995), stemming from research into virtual reality and augmented reality (projection of VR environments onto the real

world) [see chapter X for a further description]. See also Emmett (1994) and Spinney (1997) for further reviews of this application. Tom Riess himself has suffered from PD for over 16 years and has tried to develop this approach to “un-freezing” at the Human Interface Technology Lab (HITL) in Washington University.

As well as these primary symptoms, there are a range of secondary symptoms which patients may exhibit. These include; depression, sleep disturbances, speech problems, drooling, dementia, stooped posture, dizziness, breathing problems, difficulty swallowing, weight loss, constipation and sexual problems. Many of these secondary symptoms may only become apparent in the later stages of PD.

Apart from depression and dementia, most of these problems are physical ones, however, intellectual and cognitive changes may also occur, which include for example loss of drive, enthusiasm and curiosity.

This study aims to determine whether cognitive processes, specifically visuospatial cognitions, differ in those individuals who suffer Parkinson’s disease compared with ‘normal’ control participants. However, this question is not as straight forward as it may initially appear, and previous research highlights a split between those researchers who have discovered cognitive deficits and those who have failed to observe differences between Parkinson’s patients and control participants.

Lazaruk (1994) reviews this debate with the aims of presenting the evidence for and against visuospatial impairment in PD patients. The results of 17 studies were compared, and a table presented (Lazaruk, 1994; pp 42-43, Table 1) which summarised their findings. What becomes evident is that across the range of studies examining spatial abilities, the methods of measurement of these abilities differ between different authors. It is therefore impossible to say that Parkinson’s patients

suffer from a definitive impairment since studies have all tapped different sub-components of spatial cognition.

A wide range of clinical tests have been used to assess spatial skills, including tests of route walking, rod orientation, line orientation, facial recognition, mental rotation and angle perception. The flag location task described in the present study may involve a number of spatial skills, one of which involves the perception of angles, a component of the visuospatial test battery that Boller, Passafiume, Keefe, Rogers, Morrow, & Kim (1984) used.

They designed their study to examine the influence of both perceptual and motor factors on visuospatial impairment in patients with Parkinson's disease. Their reasoning is that the symptoms of PD itself often lead to restricted or slowed physical movement (bradykinesia). It is inevitable that on spatial tests that involve a heavy motor component, PD patients will perform worse than matched normal controls. Such performance cannot itself be taken as a sign of deteriorating spatial cognitive processes, but merely as a reflection of secondary motor dysfunction. Boller et al (1984) argue that the majority of spatial tests are based on complex motor responses which, due to the nature of PD, may effect patients' abilities to respond. They use "drawing tests" and "route walking" as two examples of clinical tests with heavy motor loading.

A division has therefore been highlighted between motor free tasks and motor dependent ones, with the suggestion that the former type is a more accurate measure of pure visuospatial performance. It is often difficult to define a task as being purely perceptual or purely motor in nature. The results of a factor analysis carried out by Waterfall & Crowe (1995) showed that many tests contained both elements. A "pure" visuo-spatial task can be described as one which does not require any motor skills and

which is an honest measure of strict visuo-spatial ability. Obviously timed tests, such as those involving reaction times, are not altogether useful at differentiating real spatial problems in PD patients, therefore motor-free testing procedures are best suited.

Boller et al (1984) divided a number of visuospatial tests (ranging from simple to complex) into 2 sub-categories, which they labelled “visuoperceptual tasks” and “visuomotor tasks”. The visuoperceptual tasks were “...*relatively free of a motor component*” and “...*responses were limited to pointing or saying yes or no*”. Both sub-categories of tests were administered to 30 PD patients and 30 controls and the presentation order of the visuoperceptual and visuomotor tests was counterbalanced to control for practice effects.

After converting all test results to z scores, the PD and NC (Normal control) groups were compared using a 2-WAY ANOVA. Controls performed significantly better on both visuoperceptual and visuomotor ($F[1,58] = 4.8$; $p = .029$).

The team also concluded that some of the simpler visuospatial tests were better at distinguishing between PD patients and controls than the more complex spatial tests.

A later study [Levin, Llabre, Reisman, Weiner, Sanchez-Ramos, Singer, & Brown (1991)] looked at a larger sample of 183 PD patients and 90 controls, comparing their performance on six visuospatial tasks. They used a diverse battery of tests, none of which were timed and only one of which relied on a motor component. They chose to focus on duration of disease and classified patients into early (1-4 yrs.), middle (5-10 yrs.) and advanced (10+ yrs.) stages of progression. Their results suggest that both dementia (which was recorded using the MMSE [Mini-Mental State Exam]) and disease duration contribute to the decline of spatial ability, but that the interaction

between these factors is highly complex, in that some abilities decline independently of intellectual changes (i.e. dementia).

Natsopoulos, Bostanzopolou, Katsarou, Grouios, & Mentenopoulos' (1993) study tested 27 PD sufferers and 27 controls on a battery of 8 spatial tests including block design, picture arrangement, object assembly and mental rotation. Participants were matched for age, sex, education and non-verbal intelligence (as measured using Raven Standard Progressive Matrices). The authors argue that previous conflicting evidence, with regards to visuospatial deficits, may be as a result of "*...methodological approaches*" or even "*...to methodological shortcomings*" and that more sensitive statistical analysis needs to be used to interpret the data. They therefore chose to analyse their results using a regression analysis amongst other statistical techniques.

Their analysis highlighted significant correlations between 6 of the 8 tests, in the PD group, suggesting that they were all tapping spatial cognition. They found that Parkinson patients were impaired on tasks requiring the construction of whole entities (block design, object assembly) and that visuoperceptual attention was also impaired (picture completion, closure of geometric figures test). However, when they analysed data from hemispheric subgroups (left hemisphere more effected or right hemisphere more effected) of PD participants, no significant difference in performance emerged. Consistent with the previously cited studies, their PD patients performed worse on almost all of the spatial tests. They conclude by suggesting that the factor analysis used in their study implies that differences between patients and controls are quantitative in nature and that the most sensitive criteria with which to discriminate PD patients from normal controls are L/R, back/front Euclidean orientation, 3D mental rotation and immediate visuospatial recognition memory of mirror image patterns.

Giraud, Gayraud, & Habib (1997) carried out a spatial experiment using Parkinson's patients, which has similar task characteristics to those of the tray task described in this study. Their experiment involved participants learning the positions of 12 locations on a map and then asking them to reproduce the spatial layout. One condition involved participants remembering labelled locations and the other, locations with no semantic label. Their PD patients performed no differently to controls on the more effortful, semantic labelled task, however the authors found that PD participants performed less accurately in the simpler non-labelled task. They concluded that a specific visuospatial deficit was present in PD patients and that '...the disappearance of the functional link between spatial location processing and object identity processing' could explain their data.

A later study by Raskin, Borod, Wasserstein, Bodis-Wollner, Coscia & Yahr (1990) also highlighted visuospatial deficits in Parkinsonians when they were administered three neurological tests, developed by Benton et al, which included the Benton Line Orientation Test. All of the tests were mainly free of a motor component and had adequate normative data available. They divided their patients into 3 sub-groups according to scores on a previous test of perceptual discrimination. The 2nd subgroup, whose perceptual capabilities were intact according to the perceptual discrimination test, showed lower spatial orientation performance. Raskin et al also conclude by suggesting that the age of the patient and the duration of their symptoms may interact with the PD disease process and that each may have a different effect on cognitive function. They also argue that the differential findings of previous studies (presented later in this introduction) may be due to researchers not taking basic visual perception skills into account.

Perhaps one possible explanation for the inconsistency of results between different studies is that there are a number of influencing factors which are not always rigorously controlled for by all researchers. Methodological problems have been highlighted by Waterfall & Crowe (1995) and they state that “...*the literature has been seriously undermined by a number of methodological and theoretical faults...*”

Lazaruk (1994) concludes her paper by suggesting that there are a number of factors that need to be taken into consideration when assessing the visuo-spatial skills of Parkinson disease patients.

One such factor is that the presence of symptoms of depression in some sufferers may lead to general poorer performance compared with control subjects. Boller et al's (1994) study showed that PD patients scored higher on measures of depression than controls, however they propose that poor performance was not related to depression. Natsopoulos et al's (1993) study also failed to control for depression.

Another factor to be noted is that variations in the progression of the disease may play a role in the presence/absence of spatial problems. For example, later stage patients may suffer from a form of dementia, which could affect scores on some spatial tasks. Boller et al (1994) also chose to look at stages of disease progression and so classified their patients according to whether they were in stage 1, 2 or 3 of the disease. Overall analysis didn't highlight any significant differences across stages. They also concluded that impairment on tasks was not related to a general decline in intellectual abilities, as PD patients performed well on measures of intelligence. Visuospatial deficits can thus be distinguished from dementia. It is therefore important to note that “...*cognitive impairment in the form of spatial ability is independent of intelligence*” [Natsopoulos et al (1993)], but that intellectual decline in the late stages of the disease will compound the observed deficits.

Finally Lazaruk (1993) expresses a concern that more stringent controls for levels of medication need to be addressed when testing spatial skills; she also points out that problems of fatigue have not been controlled for adequately enough in past studies. In the present study, participants were given the option to stop if they were too tired and to rest between the tasks.

However, alongside these studies which have highlighted differences in the spatial cognitions of Parkinson's patients, there are a number of studies which have failed to find such differences. Della Sala, Lorenzo, Giordano, & Spinnler (1986) carried out an investigation using 25 Parkinsonians, comparing them with normal controls on a number of neurological and psychometric tests (including tests of intelligence, memory, language & learning). Their 2 experiments involved a more advanced version of Benton's Line Orientation test [Benton, Varney & Hamsher (1978)], which involved having to predict where a slanted line segment would intercept a horizontal line if the line were extended to cross it. Della Sala et al considered this a 'directional forecast' test. They tested participants using 18 line segments, each of 3 different lengths and measured spatial skill in terms of an 'inaccuracy score', which was the mean distance from where participants estimated the intercept to be and the actual intercept. Their results disagreed with previous findings, suggesting that Parkinsonians performed no worse than normal controls, and therefore implying that a specific visuospatial deficit is not a characteristic of PD. The authors conclude that '...the lack of difference...may be due to careful selection of patients' and attribute the discrepancy to sample bias. However, their findings did suggest that there was a tendency for Parkinsonians to be more sensitive to changes in the length of the line stimuli segments, with shorter stimuli lines resulting in greater accuracy errors. Della Sala et al finish off by suggesting that the reason why mild Parkinson's patients are

insensitive to high spatial load tests is “...*simply because they do not have any true spatial disorder.*” Boller et al’s (1984) study also discovered that PD patients could not be distinguished from normal control on the purest spatial tests, that is those with little motor output.

The study by Brown and Marsden (1986) also disputed the evidence of the ‘pro-deficit’ experiments. They tested the reaction times of both PD patients and controls on a spatial reaction time experiment, as well as measuring intellectual function and motor ability. The two groups were well matched and only differed on mean performance IQ. As was expected, the Parkinsonians performed worse on the motor tests, despite being on levodopa medication. However no differences were found for PD patients on the choice reaction time measure and the simple reaction time measure, which suggested that Parkinsonians have no impairment in differentiating between left and right. When the number of actual errors was compared for the two groups on the spatial reaction time task, Parkinson’s disease patients actually performed slightly better than the controls and were no less accurate. The authors consider that verbal strategies could have been used to perform the task but their evidence suggests that this was not the case and that spatial strategies were utilised. They also refute the possibility of a speed/error trade-off as total reaction time and error rate correlated positively, suggesting that the slower the patient carried out the task, the *more* errors they made. In conclusion they point out that their results should not be generalised to visuospatial functions in Parkinson’s patients as a whole, and that future research needs to focus on the nature of *specific* spatial deficits in clinical patients.

A second set of clinical patients used in this study consisted of a closed head injured group. These cases make up a large percentage of admissions to UK hospitals, with

over 150,000 admissions being diagnosed as suffering from Closed Head Injury (CHI) [Richardson, 1990]. The majority of cases (over 70%) are the result of road traffic accidents (RTA's), however domestic accidents, assault, occupational accidents and recreational accidents are additional causes. CHI can be defined as damage to the brain resulting in non-exposure of the contents of the skull (as opposed from an open injury such as a penetrative bullet shot in which the dura matter of the brain is exposed). The type of damage tends to be more diffused across the brain, whereas penetrative damage more often results in localised brain damage. Richardson (1990) defines CHI as “...an injury to the head in which the primary mechanism of damage is one of blunt impact” (Chapter 1, p3). The primary damage to the brain resulting from blunt head trauma is shearing and tearing of the blood vessels and nerve fibres (diffuse axonal injury) in the brain. Levin (1982) discusses the pathology of both primary and secondary damage, including intercranial haemorrhage, edema (brain swelling due to excess water) and hematomas. Teasdale & Mendelow (1984) summarise the pathophysiology of head injuries [Brooks, 1984 Chapter 2]. The result of primary and secondary brain damage is often not complete loss of a specific function, such as language, but more of a reduction in the proficiency of a whole range of functions and abilities. A general decline in visuospatial ability may therefore be apparent in patients who have suffered head injuries, as well as a slowing down of other functions such as language/speech.

Closed head injury has been shown to have a number of psychological sequelae including problems with attention, information processing, language, memory and executive functions [Levin (1991), Gronwall (1987), Levin, Mattis & Ruff (1987); see also Levin, Benton & Grossman (1982)]. Visuospatial deficits have also been observed in patients with CHI. Bowen, Clark, Bigler, Gardner, Nilsson, Gooch &

Pompa (1997) reported visuospatial deficits in children, and Cremona-Meteyard & Geffen (1994) even found visuospatial deficits in football players after very mild head injury.

Lehnung, Leplow, Dierks, Herzog, Grabs, Benz, Ritz, Johnk, Mehdorn & Ferstl (submitted) examined the effects of severe head injury using the Kiel Locomotor maze described in Chapter 6. Twelve children aged between 6 & 12 years were compared with a normal sample of children to assess the spatial strategies used by them in the locomotor maze. All of the CHI group performed worse on all measures and all had larger inter-response intervals.

Skelton, Bukach, Laurance, Thomas & Jacobs (2000) investigated the behaviour of 12 patients with traumatic brain injury using a virtual reality experiment. Navigation was via a joystick control, which did not allow backward movement, mimicking the movement of a rat in a water maze. Their results showed that patients with CHI were worse than age / sex-matched controls at finding a hidden platform in a circular virtual arena. The team suggested that "...the brain-injured participants had difficulty acquiring, remembering, or using a cognitive map of the environment." (p. 168). This proposition was supported by the patients' inability to reconstruct the room layout using cards to represent the walls, floor, arena and target. Reid, Wright & Whalley (1995) also investigated clinical patients using a virtual watermaze ('Arenamaze') and found that patients with Korsakov syndrome showed impaired spatial abilities, compared with that of a control group.

In order to compare performance on the two virtual reality tasks used in this study, a standard clinical test of visuospatial performance was administered. This was Benton's Judgement of Line Orientation Test, developed by Benton, Varney, &

Hamsher (1978). Benton et al developed this test following a previous experiment which examined the visuospatial skills of patients with right hemisphere brain damage [Benton, Hannay, & Varney (1975)]. The findings of the 1975 study showed that patients with unilateral right hemisphere damage performed worse in identifying the slope of lines presented to them on a tachistoscope. This led Benton's team to develop a similar test that could be used to differentiate between visuospatially deficient patients and non brain damaged individuals, but without the need for a tachistoscope (i.e. a simple bedside test procedure).

Benton used two forms of the test, Form H and Form V. Each has 35 items, 5 practice and 30 test items. The two forms differed merely in the presentation order of the stimuli cards, but were otherwise identical and always progressed in difficulty. The five practice items consisted of full lines matching two of the lines on the multiple choice response card. However, the test items consisted of two partial line segments (half the length of the lines on the response card) taken from the beginning, middle or end of corresponding full-length lines from the response card. The version of the test used in this study was more similar to the Benton et al (1975) study, as partial line segments were not used. This test was used due to its high levels of reliability as measured by a test-retest method providing a coefficient of 0.9. (Split-half reliability for Form H = .94 & for Form V = .89) [Benton et al (1978)].

Benton, Hamsher, Varney, & Spreen (1983) discuss classification of scores for those suffering from brain damage. According to their standardisation, scores below 20 (on the 30 item version) are classified as borderline, moderately defective or severely defective (for scores below 17). They also discuss the results of carrying out the test on children of different ages, finding that an average adult performance is reached around the age of 13.

The test was also found to reliably differentiate between left and right hemisphere disease patients [Benton et al, 1983] however not as well as the original tachistoscope study which showed defective performance in 61% of right hemisphere cases (as opposed to 29% in the partial line orientation test).

The purpose of this study was to extend the investigation of visuospatial deficits in clinical groups of patients, specifically those with Parkinson's disease and those with closed head injuries.

Hypotheses:

It was hypothesised that both Parkinson's patients and Head injured participants will perform significantly worse on all three tests of spatial cognition. It is also expected that neither groups of control participants will differ in performance across all 3 tests administered.

3.2 Virtual Golf Course Task

3.2.1 Method

Participants:

This study looked at 4 separate groups of participants, in order to determine whether they showed spatial deficits in a computerised task. The four groups were (1) Parkinson's patients (2) Head Injured patients (3) Control Group A and (4) Control Group B.

Group (1)

9 participants (6 males and 3 females) who had been previously diagnosed as having Parkinson's disease were used as an experimental group in this study. Mean age of these participants was 53.89 years, with a standard deviation of 9.51. All experimental participants were recruited by approaching local neurologists, who then provided a list of patients diagnosed with PD under their care. Patients were in the relatively early stages of Parkinson's disease, according to the information provided by the medical consultants.

Group (2)

12 participants (8 males and 4 females) who had previously suffered brain damage, mainly as a result of road traffic accidents (RTA's), were approached at a voluntary day centre in Leicester and recruited as a second experimental group in this study. The mean age of this group was 35 years, with a standard deviation of 16.02.

Group (3)

12 participants (6 males and 6 females) were also recruited as normal controls, none of whom had had any previous diagnoses of Parkinson's disease or any other neurological disorders. The mean age of the controls was 45.67, with a standard deviation of 11.93. This acted as the older control group.

Group (4)

18 participants (8 males and 10 females) were tested in the study and acted as a younger control sample. Again, none had histories of any neurological disorders. The mean age of the younger controls was 19.22, with a standard deviation of 1.59.

Participants in all groups had normal or corrected-to-normal vision.

Design:

Each participant was required to estimate the position of a fixed target (flag) from 6 different locations within the golfing environment. They therefore provided 6 scores which were converted to “angular error”. The two independent variables were “position” with 6 levels, Condition/Group with 4 levels and the dependent variable was “angular error”, measured in degrees. Counterbalancing of the presentation order of the 6 locations was implemented across participants to control for possible practice/fatigue effects. So for example, participant 1 in a group was taken to positions F3, F4, F5, F7, F8 & F9 in that order, whereas participant 2 was taken in the order F4, F5, F7, F8, F9 & F3. Position order was hence rotated.

Apparatus:

The experiment was run on a Pentium class computer with a 17” monitor and keyboard /mouse interface. The program consisted of a virtual environment that was constructed using a specific software package designed for the purpose of creating virtual reality environments. The package was Superscape’s VRT (version 5) and further details can be found at the company’s web-page address <http://www.superscape.com>. A fuller description of the software can be found in Chapter 1, Section 1.5.1.

The environment bears a resemblance to the ‘Executive Golf Task’ described by Morris, Nunn, Abrahams, Feigenbaum & Recce (1999). Their task was a 2-D representation of a golf course with between 4 and 8 holes. Users had to use the touch sensitive screen to determine which hole the golfer will ‘putt’ the ball into next. They

were told that the golfer would never ‘putt’ the ball to the same hole twice in any trial. This resulted in participants having to remember the locations of the holes that have already been putted to, analogous to remembering which arms had already been visited in a radial maze experiment. Their task was a multiple-goal paradigm, whereas the Flag Location Task, presented here, is a single-goal experiment, more similar to finding the hidden target in the Olton Water Maze. The Flag Location Task is also more 3-dimensional, allowing infinite points of view of the environment, unlike the Executive Golf Task, which allowed for only one fixed perspective. The Flag Location Task is therefore proposed as being more naturalistic and ecologically valid. The Flag Location Task environment consisted of a circular arena surrounded by trees, which marked out the perimeter of the circular “golf course” environment. Within the circle of trees were placed a number of objects, randomly positioned, although the positions were fixed across all participants. Figure 3 (in appendix) shows an overhead view of the environment highlighting the environmental objects. These objects were;

1. *Post-box*
2. *Crate*
3. *Phone-box*
4. *Trafficlight*
5. *Traffic cone*
6. *Piano*

As well as these cue objects, a single white flag, which represented the target object, was also positioned amongst the other 6 objects. The flag was the object that

participants were later asked to find (target object) and was made more salient by making the flag appear to blow in the wind (i.e. it was an animated object). Navigation through the virtual space was controlled by the cursor keys, to the left of the numeric key-pad. The ↑ and ↓ keys controlled forward and backwards movement respectively, whereas the ← and → keys allowed rotation to the left and right respectively. As well as a moveable human viewpoint, activated by pressing the F6 function key, 6 static viewpoints were placed around the environment, which could be activated using function keys F3, F4, F5, F7, F8 & F9. These 6 keys allowed the experimenter to place a participant into 6 virtual positions (each facing a fixed direction) within the environment at the touch of a button. Finally, 2 other key combinations were used to control the visibility of the target flag, with Shift-I making the flag invisible and Shift-V making it visible again.

Just below the main viewing window, which displayed the environment, was a small data panel which consisted of 6 tiny windows which displayed the number of degrees that the participant had turned during the search phase of the procedure (see figures 1 and 2 in Appendix- Section 3.6). Each of these was in a different colour, representing the 6 different static viewpoints (see Table 1, below):

Viewpoint	Colour
F3	Yellow
F4	Red
F5	Green
F7	White
F8	Purple
F9	Orange

Table 1 – Table showing the colours of the 6 viewpoint / positions as displayed on the screen

The 6 static view points are also represented in figure 3 (see appendix).

Procedure:

Participants were initially introduced to the experimenter who then noted down their personal details, including their name, age, sex and date of birth. They were then asked about any medication they were receiving and were also asked whether they had any problems finding their way around (all of the PD patients were on prescribed medication). Other information, such as whether they wore contact lenses or glasses to correct vision was recorded.

Their attention was drawn to the computer and it was explained that they would be shown a three-dimensional virtual environment on the computer monitor which they would be given some time to move around and acquaint themselves with. An overhead view of the environment was shown to participants and it was explained to them that the environment consisted of a circle of trees with a number of objects within it (see figure 3 in appendix). The participant was taken to a starting viewpoint (by pressing the F6 key) and told that from this point they could move forwards and backwards, and also turn to the left and to the right, by using the cursor keys. It was explained that this was the way to navigate the environment and look around. The experimenter showed participants how to control movement of the viewpoint using these 4 keys.

They were then informed they would be given some time (up to 10 minutes) to explore the environment and that they should pay close attention to the flag, in relation to the other objects. They were told that they were to try to learn the position of the flag, so that later, when the flag was made invisible, they would be able to estimate its location from 6 different positions the experimenter would take them to.

The experimenter continued to explain that once they had looked around, they would be placed in 6 locations within the circle of trees and that they would be asked to simply rotate on the spot from the fixed position until they had covered the invisible flagpole with a crosshair which was positioned in the centre of the viewing window. It was clearly explained that from the 6 fixed positions the participant would only be able to rotate on the spot to place the cross hair over the flagpole and that they would *not* be able to move forwards or backwards from the viewpoint. This procedure would be the equivalent, in a real life task, of being placed on a fixed spot and being asked to turn on the spot to face the flag.

After this explanation of the task and the demonstration of how to navigate with the cursor keys, the experiment was begun. The participant was given up to 10 minutes to look around and the 7 objects (target object plus 6 cue objects) were all pointed out as the navigation continued. All participants were asked to explore the environment from all angles/distances so that they could recognise the objects from anywhere within the perimeter of trees. Throughout the explorative phase, the experimenter reminded the participant to keep their eye on the position of the flag, so that they could later locate it, even when it was made invisible to them.

After a maximum explorative phase of 10 minutes, the participant was told that the flag would now be made invisible (by pressing Shift-I) but that it would still be in exactly the same position as it was when visible. The search phase then started and participants were taken to 6 locations, one at a time, and asked to turn to place the now invisible flag in the centre of the screen, trying to cover the flagpole with the crosshair and to be as accurate as they could be. They were encouraged to imagine whether they had been placed near to or far away from the flag in order to help them locate its' position. As the left or right cursor keys were pressed, the fixed viewpoint

rotated by 1 degree in either a clockwise (left key) or an anti-clockwise (right key) direction and the actual angle of rotation was displayed in the corresponding coloured window below the viewing window. Each angle of rotation was noted on the record sheet. After the 6th fixed location had been visited and the participant had made their estimate of the flag's location, the flag was made visible (Shift-V key combination) to show how accurate they were. They were not shown the actual position of the flag after each of their estimates, as this would have lead to a revision phase, possibly nullifying the results.

Finally, the participant was thanked for their help and given the chance to be debriefed about the nature of the experiment.

3.2.2 Results

The angular error (irrespective of direction) was calculated for each of the six positions that participants were asked to determine the position of the flag from. This value was always between 0 and 180 degrees (as direction of error was not taken). Figure 4 (in Appendix- 3.6) shows the fixed position (the arrow indicating the direction that the view point was facing) and the angle of error that was calculated.

Cell means are displayed in Table 2 over-leaf.

The data in table 2 is also presented graphically in figure 5 (see appendix).

Condition Group	Flag Position					
	1	2	3	4	5	6
<i>Parkinson's</i>	24.22	31.11	8.33	37.44	23.89	22.22
	(13.18)	(9.64)	(2.20)	(9.59)	(6.02)	(15.56)
<i>Head Injured</i>	34.75	27.75	23.83	44.58	27.67	17.33
	(8.69)	(9.43)	(9.23)	(13.30)	(9.38)	(4.26)
<i>Control A</i>	35.17	14.08	14.50	37.33	28.25	13.33
	(12.48)	(3.47)	(4.46)	(10.27)	(13.86)	(4.82)
<i>Control B</i>	7.78	13.72	5.72	20.44	13.44	5.06
	(1.45)	(1.72)	(0.75)	(3.62)	(2.17)	(1.93)

Table 2 – Table showing mean angular error for 6 positions across 4 condition groups. Standard error of mean shown in parentheses.

The data was then analysed using a 2 way (4 X 6) mixed ANOVA (Condition as the between subjects factor).

A significant main effect was observed for the position factor with $F(5, 235) = 7.22$; $p < 0.01$. A significant main effect for the Condition factor was also observed [$F(3, 47) = 2.86$; $p < 0.05$]. No significant interaction effect (Condition X Position) was found [$F(15, 235) = 0.852$; $p > 0.05$].

Having no interaction effects, it was concluded that the main effect was a true effect and so were analysed using a post-hoc analysis to determine which pairs of factor levels differed significantly. For the between subjects factor of Condition, a Tukey's HSD test was carried out. Only the head injured (Group 2) and the younger controls

(Group 4) differed significantly [Mean difference = 8.29; $p < 0.05$]. Figure 6 in the appendix displays the means, which are summarised in table 3 below.

Condition Group	Mean angular error across all 6 positions	Standard error of the mean
<i>Parkinson's</i>	24.54	8.77
<i>Head Injured</i>	29.32	5.63
<i>Control A</i>	23.78	6.38
<i>Control B</i>	11.03	1.10

Table 3 – Table showing mean angular error for all 6 positions combined across 4 condition groups.

A number of Bonferroni t-tests were used to look for significant differences between pairs of means over the Position factor. The critical p value for unplanned comparisons is therefore 0.003, and only three pairs of means differed significantly at this value or lower. Positions F4 & F7 [$t = -3.769$; $p < 0.01$], positions F5 & F7 [$t = -4.287$; $p < 0.01$] and positions F9 & F7 [$t = 4.472$; $p < 0.01$]. Finally, means over the 6 positions were correlated with each other, most giving a significant r values of 0.35 or higher.

3.3 Assessment of spatial ability using the Benton's line test

3.3.1 Method

Participants:

The same 4 groups of participants were used as in the Golf Course task (Section 3.2)

Design:

Presentation of the 28 paired line cards was reversed for every other participant, in order to balance for order effects. This led to half the participants being presented with the cards in the 1-28 order and the other half in the 28-1 order.

The independent variable was Condition/Group and the dependent measure was Score (Correct number of answers out of 28, expressed as a percentage).

Apparatus:

A shorter variation of Benton's Judgement of Line Orientation Test was used. 29 laminated white cards of dimensions 21 x 13.5 cms were used. 28 of the cards were stimuli cards and one was a template card, which was constantly in view to the participant. The template card consisted of a 180 degree arc of 11 equally spaced black lines, each of length 2.5 cm (see figure 7 in Appendix). Starting from the left-hand line, each line was numbered above from 1 to 11 consecutively. The remaining 28 stimuli cards had 2 black lines on them, which matched the exact length and position of two of the lines on the template card. All 28 stimuli cards had a different combination of the two lines (see figure 8 in Appendix for an example stimulus card). Finally, an answer sheet for recording responses was used.

Procedure:

Immediately after carrying out the flag task, the participants were told that, in order to give their eyes a rest from the computer screen, they would now be asked to carry out a test that did not involve looking at the monitor.

The template card was placed directly in front of them on the desk and they were asked to position the card or their body so that they were looking straight at the

central line (vertical line, number 6). Participants were then informed they could see 11 numbered lines in front of them, which they were asked to point to one by one and read off the number associated with each line. This was done to ensure that all eleven lines could be correctly recognised and differentiated. Having done this, it was explained that they were about to be shown 28 separate cards, each of which had a pair of lines on it, matching the positions of two of the lines on the template card in front of them. For each of the cards, they were asked to give the two numbers of the matching lines from the template or to indicate the matching lines by pointing. Once they understood the instructions, the test was begun. The sequence of 28 cards was placed in front of them, one at a time, with the stimulus card placed immediately above the template card, parallel to it but without overlapping it in any way (see Diagram 1 below).

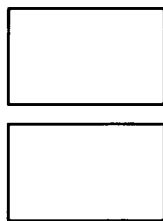


Diagram 1: Arrangement of template (bottom) & stimulus (top) cards

Participants were told that they could straighten the cards at any time, but that they were not to overlap them. The number pair given by the participant for each card was recorded on the answer sheet.

Participants were given as much time as they needed to complete this task.

3.3.2 Results

The mean number of correct responses was calculated for the 4 groups of participants, and expressed as a mean percentage correct score. A one-way ANOVA was applied to the data to determine whether any of the 4 mean scores differed significantly. Results of the ANOVA showed $F(3,47) = 3.80$, $p < 0.05$, suggesting that 2 or more of the means differed significantly at $\alpha = 0.05$. The mean scores are presented in table 4 below.

Condition Group	Mean % score on Benton's LOT	Standard error of the mean
<i>Parkinson's</i>	93.65	2.65
<i>Head Injured</i>	81.55	5.36
<i>Control A</i>	89.88	4.07
<i>Control B</i>	96.82	1.58

Table 4 – Table showing mean % score across 4 condition groups.

A follow-up post-hoc Tukey's HSD test was done to determine which paired comparisons were differed significantly. The critical q value was 8.8 and the only pairs of means which differed significantly were Group 2 (Head injured participants) and Group 4 (Younger Controls). None of the other pairs of means differed at $\alpha = 0.05$ significance. Figure 9 (see appendix) shows the means in graphical form.

3.4 The virtual tray of objects task

3.4.1 Method

Participants:

The same 4 groups of participants were used as in the Golf Course task (Section 3.2) and in the Benton Line task (Section 3.3).

Design:

The independent variable was again Condition/Group, with 4 levels and the dependent measure was the number of correct answers out of 5, expressed as a percentage of the total score. Presentation order of viewpoints (see Procedure) was counterbalanced.

Apparatus:

The experiment was again run on a Pentium class computer with a 17" monitor and keyboard /mouse interface. The environment in this section consisted of a brown coloured, flat, square, tray-like surface with 8 objects on top of it.

The objects had been positioned in such a way that from various vantage points around the tray, only certain objects were visible. In other words, from some positions around the outside of the tray, certain items obscured others, either partially or totally.

The objects consisted of geometric three-dimensional solid shapes as follows;

1. *Large pink cube*
2. *Small green pyramid*
3. *Large yellow pyramid*
4. *Reddish-orange column*
5. *Orange/white traffic cone*

6. *Small blue rectangular solid*

7. *Green bottle*

8. *Blue bottle*

Towards the bottom of the viewing window, at the right hand side, was a brown rectangular panel (2 x 6 cm). When the mouse pointer was positioned over this panel and the left mouse button clicked, the “tray” of objects would rotate from the mid-point, through a complete 360 degrees. The rotation could be halted at any point by releasing the mouse button.

The point of view around the tray could be changed at any time by the experimenter by pressing the “shift” key and, at the same time, pressing one of the number keys between 1 and 5. Each of these 5 fixed viewpoints allowed the tray of objects to be viewed from a different perspective. For some of these viewpoints, changes had been made to the arrangements of objects on the surface of the tray. For the Shift-1 view, the blue rectangular solid had been removed and should normally have been visible from this point of view. For the Shift-5 view, the large green pyramid had been moved to the left. Two example screen shots can be seen in Figures 10 & 11 (Appendix).

Procedure:

Participants were shown the computer and were informed that what they saw on the monitor was the computer equivalent of a tray of objects. They were told that there were 8 objects altogether and the experimenter pointed out all 8 objects to them, whilst explaining how to rotate the tray using the mouse. Once the participant was sure how to turn the tray, the main aim of the test was elaborated upon. Participants were informed that they were to spend some time attempting to learn the relative positions of the 8 objects so that later, if anything was moved or changed, they would

be able to say what. It was explained that during the actual test they would be placed at different points of view around the outside of the tray and that they would be asked questions about the arrangements of the objects. Participants were also told that this was not a memory test for the names of the objects themselves and that they could be reminded at any point what the 8 objects were. The participant was then given a maximum of 10 minutes to rotate the tray of objects and to learn about the arrangement of the items.

Once the participant was ready to begin, the experimenter pressed the appropriate key combination on the keyboard, which took the viewpoint to one of the 5 pre-set views. The participant was then asked a question relating to the specific view and the answer was recorded. This was repeated for the remaining 4 viewpoints. The questions associated with each viewpoint are presented in table 5 below:

Viewpoint	Question Asked
Shift-1	Something that you should be able to see from this viewpoint has moved or been removed. Can you say what?
Shift-2	Where is the green bottle?
Shift-3	What object is directly behind the blue rectangular solid?
Shift-4	Where is the green bottle?
Shift-5	Something about the arrangement of the objects has altered. Can you say what?

Table 5 – Table showing questions asked of participants in ‘tray task’.

On occasion, the participants were asked to elaborate on their answer in order for the experimenter to determine whether it was correct or incorrect.

3.4.2 Results

A raw score out of 5 was recorded for each participant and a mean % score (percentage of correct answers) per participant group (2 controls, Parkinson's and Head Injured) was calculated. Mean raw scores and standard errors are displayed in table 6 below.

Condition Group	Mean score	Standard error of the mean
<i>Parkinson's</i>	3.00	0.41
<i>Head Injured</i>	2.67	0.28
<i>Control A</i>	4.17	0.32
<i>Control B</i>	4.67	0.11

Table 6 – Table showing means scores on 'tray task' across 4 condition groups.

A one-way independent groups ANOVA was used to determine whether the observed differences in mean scores were significant. The ANOVA highlighted a significant effect of group with $F(3,47) = 14.098$; $p < 0.01$. A post-hoc Tukey's HSD test was carried out to establish which pairs of means differed significantly. Of these multiple comparisons, both control groups differed significantly from both the Parkinson's and the head injured groups; $p = 0.031, 0.001, 0.0001$ & 0.0001 for all four pairs that differ. The two control groups and the two experimental groups did not differ significantly from each other (all p 's > 0.05). The differences can be seen in figure 12 in the appendix.

3.5 General Discussion

It was hypothesised that both our clinical samples of participants would perform worse on the flag location task than the control groups. This hypothesis was partially supported, with the results indicating that the head injured patients performed worse than one set of controls. However, no significant differences were found between the control groups and the Parkinson's sufferers. One other interesting observation from the flag location task results is that there is a main effect for the position of the viewpoint. This implies that the task is easier to perform from some locations than others. A possible explanation for this is cue salience. If some cues were more salient than others, this may have led to participants spending more time observing the environment from close to a particular cue. A future study which randomised the arrangement of the environmental cues between participants may diffuse this effect.

For the Benton line test, the results followed the exact same pattern, supporting a significant difference in performance of the head injured participants compared with one of the control groups, but not supporting any differences in performance of Parkinson's patients.

However, the results of the tray task experiment fully support the hypothesis set in the introduction, that both clinical groups significantly differ in ability from the controls.

So, with regards to the Parkinson's patients, why do we only see a significant drop in performance for the tray task? This could be due to the fact that this group had no recordable spatial deficit or perhaps that the VR test was insensitive to such deficits.

We have chosen to accept the former explanation on the basis that the test clearly differentiated between a clinical and a control sample (the head injured vs. control) and therefore has the potential to detect differences in spatial abilities. The inference

that the Parkinson's patients had no recordable spatial deficit is also backed up by the results of the Benton's Line Test experiment, which again showed no differences between the control groups and the Parkinson's group. This result of course contradicts the evidence supporting spatial deficits in Parkinson's disease patients. However, studies have suggested that the course of the disease may effect the results of neuropsychological tests of spatial cognition and so this study does not support an out and out rejection of the 'spatial deficits in Parkinson's disease' hypothesis. The group of Parkinson's patients used in this study were all younger sufferers and in the relatively early stages of the disease. As a follow-up from this study, it would be interesting to re-test this group of patients in the later stages of disease progression to see whether their performance alters or whether the results remain stable irrespective of the course of the disease. The result of Levin et al's (1991) study suggests a complex interaction between disease duration and other factors such as dementia.

One other explanation to be considered is that spatial tests do not necessarily all tap the same 'spatial ability' and that perhaps only certain elements of spatial cognition are deteriorating in Parkinson's patients. The results of the tray experiment suggest that some measurable spatial deficit does exist, as both Parkinson's and head injured participants performed significantly worse than the controls. This draws us towards the idea that this experiment is perhaps tapping a different element of spatial cognition than the flag location task. The tray task relies strongly on abilities such as mental rotation than the flag location task or the Benton Line test (which both contain an angular perception element) and requires the participant to have a detailed cognitive map of all the objects and their relationship to each other.

It is therefore difficult to choose between opposing perspectives with respect to the existence of spatial deficits in Parkinson's patients. Our evidence suggests that results

of such tests depend heavily on the type of test used and the particular ability being tapped. Finding a pure test, that is one that measures a single sub-ability of spatial cognition, is not easy. It has already been addressed in previous research [Boller et al (1984)] that motor abilities may confound results and that tests need to be designed which are not reliant on such abilities. Perhaps it is appropriate to focus more clearly on the idea of spatial ability being a global concept with a number of sub-measurable components, some of which may or may not deteriorate in clinical patients. Lazaruk (1994) also suggests that the ‘...multidimensionality of visuospatial ability needs to be considered’ and Hovestadt, De Jong & Meerwaldt (1987) suggest that ‘Many tests probably screen different aspects of spatial behaviour.’

One factor, which may have influenced the results, is that of the demographic variable of age. It would have been ideal to age match participants more closely in this study, however a limited sample size made this a difficult task. One could argue that the differences between performance of the clinical and control samples were due to a difference in mean ages. However, it was shown that performance of the two control samples themselves did not differ significantly across all 3 experiments, suggesting that age itself was not a factor which lead to differences between the samples. The mean ages of the control groups were less similar than those of the pairs which showed significant differences (Head injured vs. Group (4) controls).

It is clear from this study that VR procedures can be used to measure spatial abilities. What is more difficult to conclude is which specific abilities are being measured. The VR tests used in this study offer many advantages over standard neuropsychological tests, such as those carried out by earlier researchers [Levin et al (1991); Boller et al (1984). See also Lazaruk (1994)], some of which have been discussed in Chapter 2. The flag location task could be carried out in a large scale real environment but it

would be impossible to control the environmental cues in the same way as was done using the VR version. Placing a participant in a specific fixed location would also be an arduous task and the actual physical movement through the environment would be a most difficult one for Parkinson's sufferers especially. Testing of spatial abilities in large scale real environments is therefore theoretically possible but practically difficult, possibly physically distressing and time consuming.

The tray task is a good example of a testing procedure that simply could not be carried out in the same way in the real world. One advantage that VR offers is complete experimenter control over what the participant can see in the environment, a necessary component of the tray task. If a real version of this task was performed, participants could move their heads at any point to change the perspective of what could be seen, and which would then nullify the results. Other environmental cues may also be used in the real world, which may lead to extra strategies for participants remembering locations and thus diffusing the results. The VR tray task allows a static perspective of the tray to be observed, which is unchanging even if the participant moves his/her head. This VR task also allows perspectives to be changed in an instant, so that no extra spatial information can be learnt between changes, unlike a real version in which a time delay would be needed to manipulate the position of the tray and the objects upon it. It would not be feasible to carry out this task in the real world, but VR environments have been shown on many occasions to allow the learning of spatial information and are therefore an ideal alternative to real-world testing.

Possible future research stemming from this experiment could involve testing larger patient samples who had been previously well assessed using standard neurological test batteries, to compare how sensitive the VR tests are in relation to non-VR ones. Correlational analyses on standard neuropsychological tests of spatial ability against

the VR ones used here would help to highlight what sub-components of spatial cognition the VR tests were tapping. There are also a number of variations of the two VR tasks that could be implemented. For example, a different set of cue objects could be used in the flag location task in order to determine whether cue salience is a factor in locating the position of the target. Our results certainly suggest that the position of the fixed viewpoint has an effect on ability to determine the exact location of the flag and possibly due to the salience of nearby cues.

In conclusion, it is clear that the head injured participants show spatial deficits on all of the three tests administered. The Parkinson's patients' performance on the tests, however, only differs from the controls on the Tray test, suggesting that measurable deficits do exist, but that the deficits are very specific and may not be evident in all tests.

3.6 Appendix

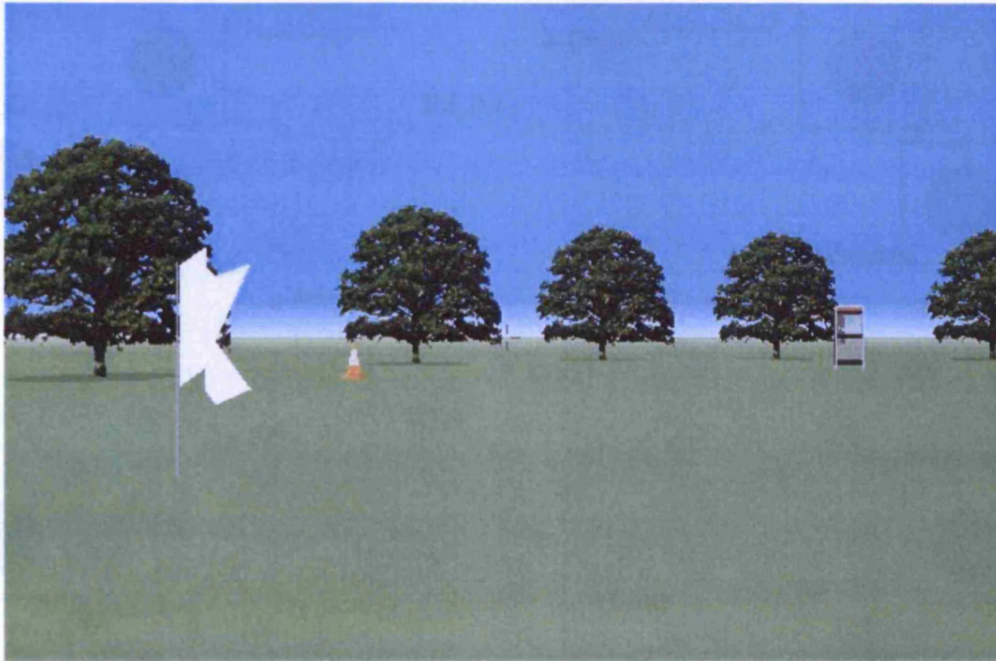


Figure 1- Flag Location Task screen shot showing flag



Figure 2- Flag Location Task screen shot showing traffic lights and results panel

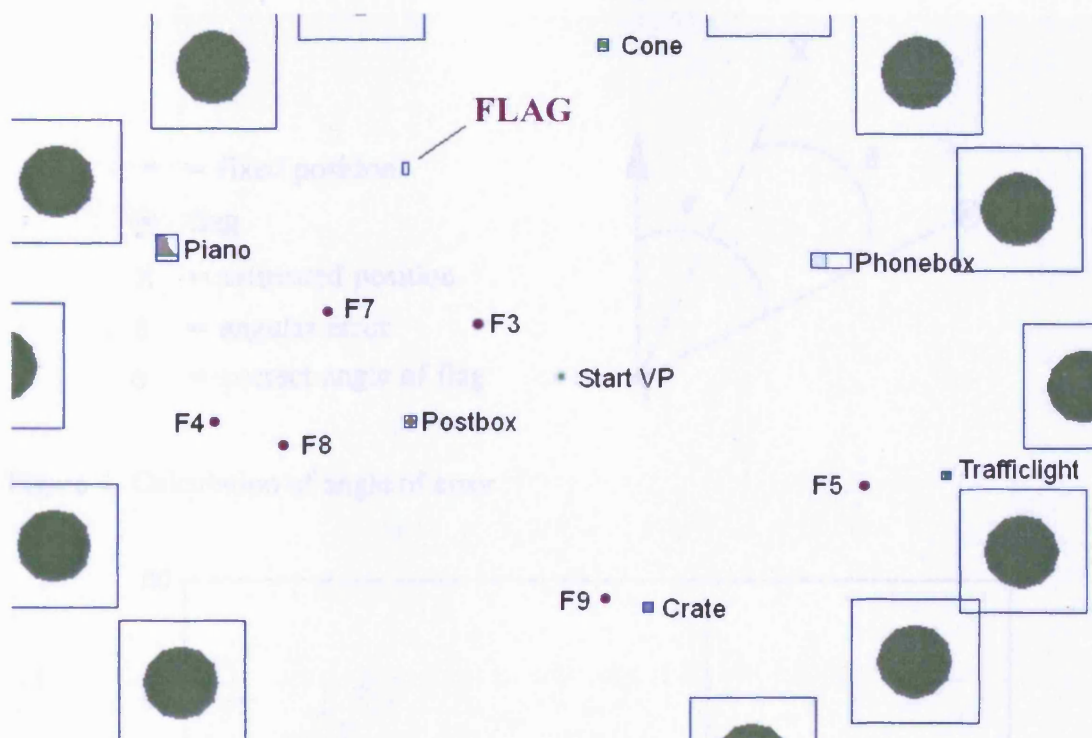


Figure 3 – Overhead view of flag environment showing objects and viewpoint positions labelled F3-F8. Partial view of the trees can be seen at the perimeter.

PTO.

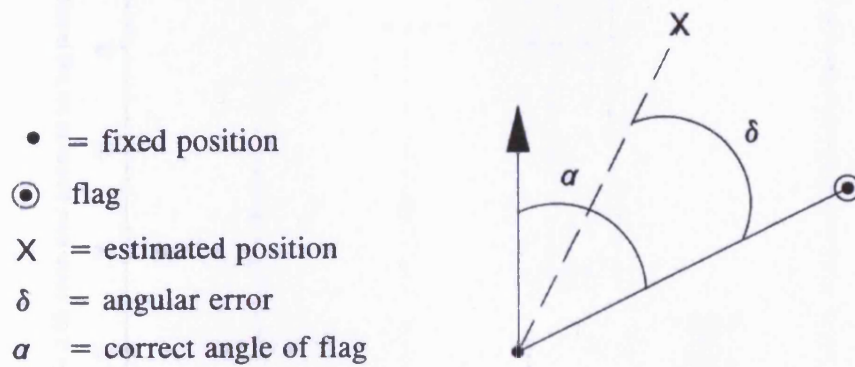


Figure 4- Calculation of angle of error

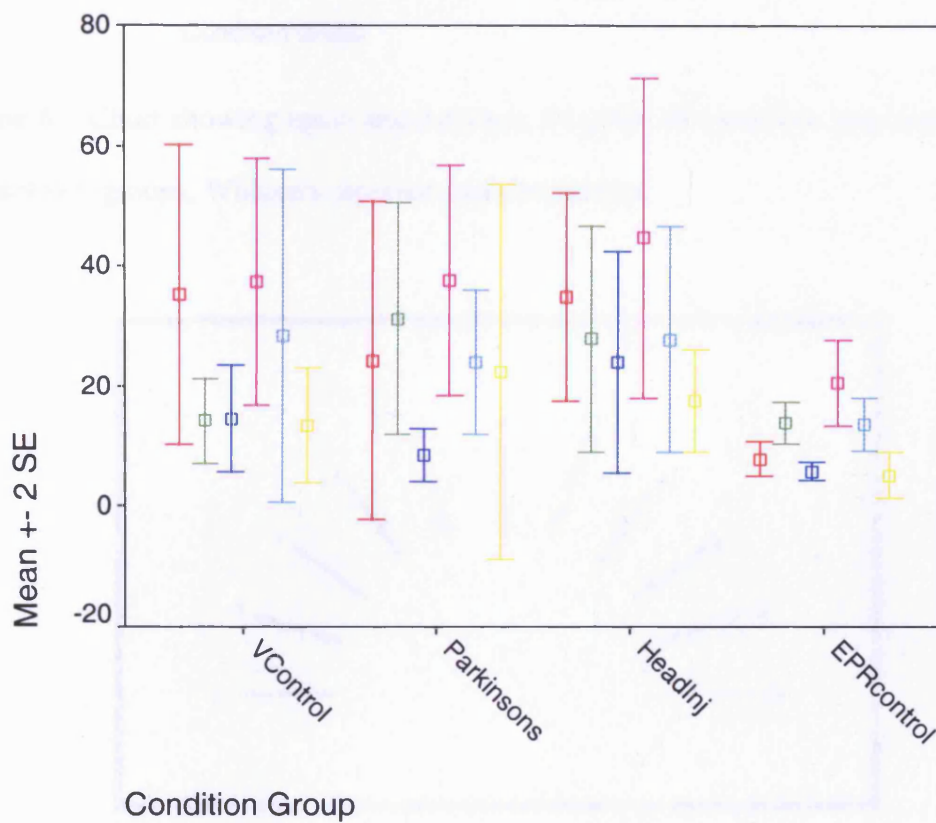


Figure 5 – Chart showing mean score for each position across 4 condition groups. Colored squares represent positions 1-6 respectively per condition group. Whiskers represent standard errors.

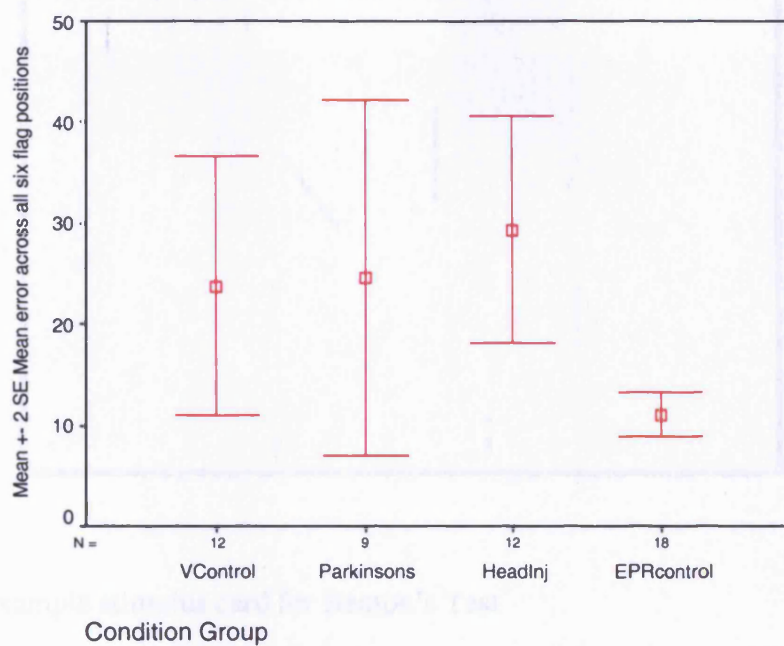


Figure 6 – Chart showing mean angular error score for *all* positions combined across 4 condition groups. Whiskers represent standard errors.

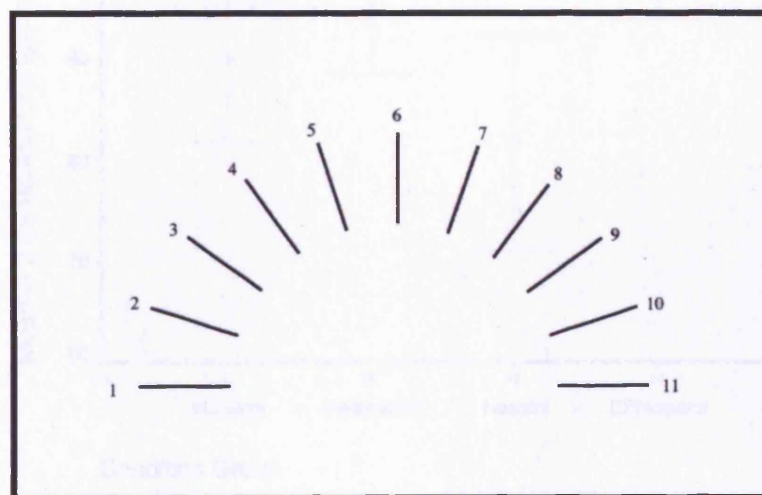


Figure 7- Template for Benton's Test

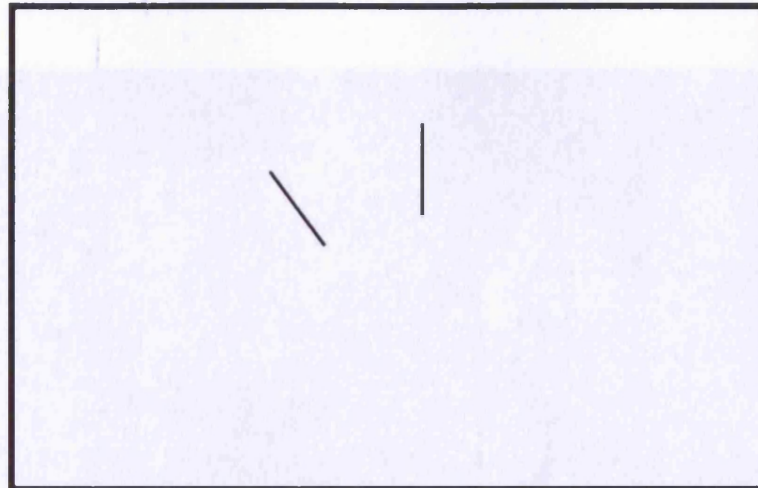


Figure 8- Example stimulus card for Benton's Test

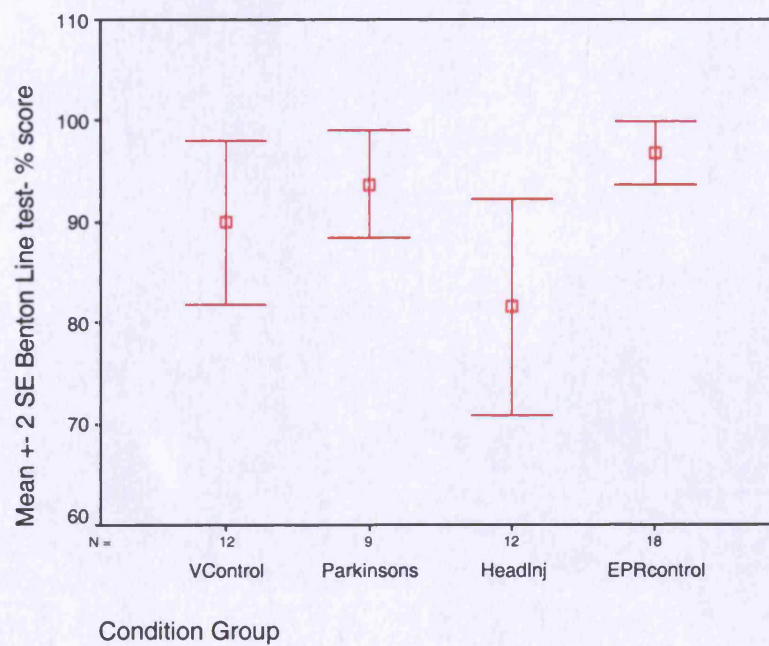


Figure 9 – Chart showing mean % error score on Benton's LOT across 4 condition groups. Whiskers represent standard errors.

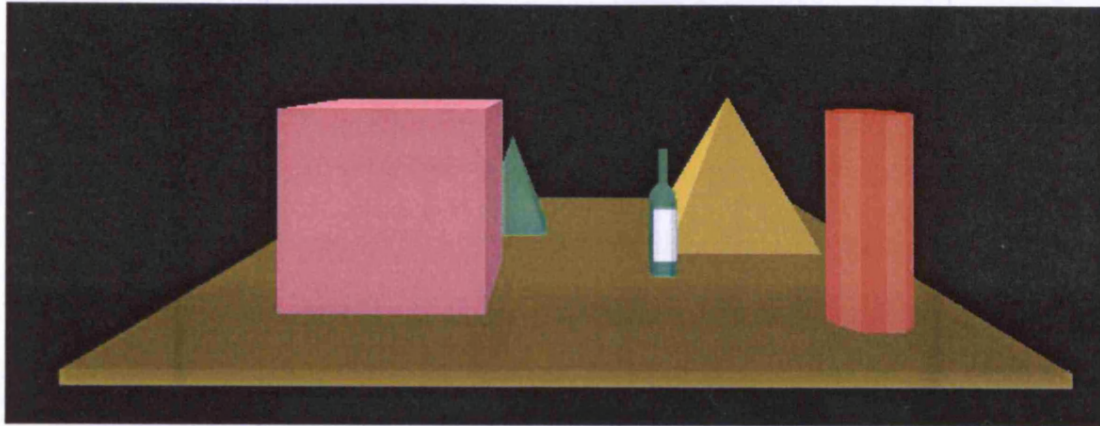


Figure 10 – View of tray task

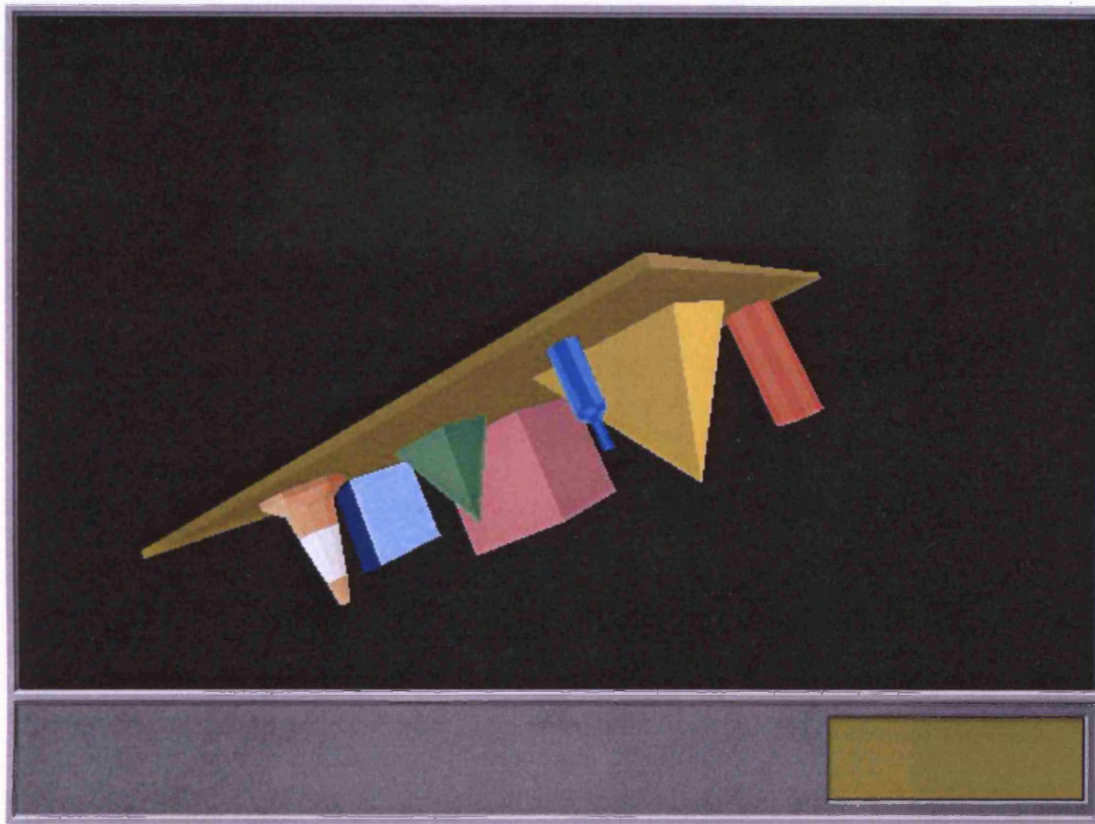


Figure 11- One of the set of views of the tray

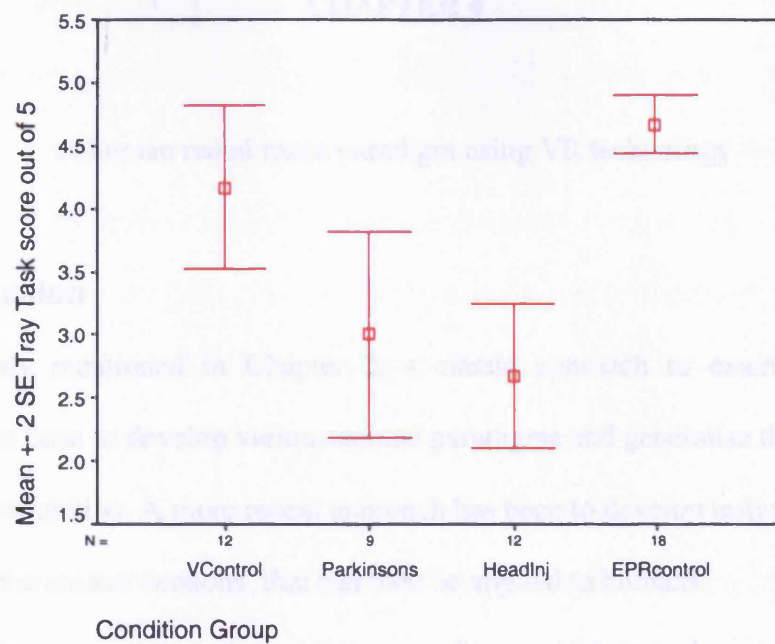


Figure 12 – Chart showing mean raw score on Tray Task across 4 condition groups.

Whiskers represent standard errors.

CHAPTER 4

A human radial maze paradigm using VR technology

4.1 Introduction

As previously mentioned in Chapter 2, a classic approach to examining spatial cognition has been to develop various animal paradigms and generalise the findings to the human population. A more recent approach has been to develop testing paradigms, based upon the animal versions, that can then be applied to humans.

There have been a number of animal test paradigms which have been used since the 1970's to develop theories of animal spatial cognition, including the cross maze, the radial maze and the water maze [see Thinus-Blanc (1996), Chapter 3]. The radial maze and the water maze will be discussed briefly, as these two paradigms have formed the grounding for work described in this and the proceeding chapters. However the difficulties in replicating these paradigms for a human sample are those of cost and of space. Navigational tasks such as the water and radial arm maze require an arena large enough for a human to navigate within posing a problem for most psychological research teams. Other problems such as controlling proximal and distal cues in open spaces occur when large scale real world environments are used to address spatial learning in humans. An ideal solution is to use a medium within which classic animal paradigms can be tested accurately, but one which will allow a large degree of control over the testing scenario. This is where virtual reality environments are highly appropriate, as they offer a high degree of ecological validity whilst maintaining strict control over the testing situation [Rizzo & Buckwalter (1997)].

4.1.1 Two classic animal paradigms

The radial arm maze was developed by David Olton [Olton & Samuelson (1976), Olton (1977)] and is used to examine how animals (initially rats) learn and store information about separate spatial locations. Its basic structure, which since has been added to and subtracted from, involves eight equally spaced locations which radiate around a central platform. 8 arms connect the central platform to the 8 distinct locations and the end of each arm reaches a food container which may be baited with food pellets. The ends of the arms cannot be seen from the central platform and so the animal must navigate to the end of the arm in order to determine whether any food has been stored there.

In the classic experiment [Olton (1977)] all arms of the radial maze are baited (food stored there) and the rat has to visit each arm of the maze to retrieve the food pellet. In order to prevent redundant choices (re-visiting an already visited location) the animal has to store some sort of representation of which arms have been visited and which remain unvisited, in its brain. Numerous procedures have been used in conjunction with the radial maze paradigm to determine how animals learn the locations of the visited and unvisited arms, such as using a subset of baited arms to examine working and reference memory errors [see Foreman & Ermakova (1998)]. The radial arm maze is an example of a 'multiple choice' task [Horner (1984)] in which numerous trajectories are taken to solve the task (much like natural foraging behaviour). In contrast with this is the Water maze [Morris (1981)], which requires a single trajectory to solve the task.

The Water Maze is a single-goal task which requires an animal to swim in a circular tank of water until it reaches a hidden platform which it can stand on to escape the discomfort of the water. It is not really a maze but more of an open arena with a single

response requirement [Schenk (1998)]. A number of 'acquisition' trials are completed to allow the rodent to learn the location of the hidden platform and these are followed by a 'probe' trial where the platform is removed and the behaviour of the rat is recorded with respect to which maze quadrants it spends most of its' searching time in. Normally the animal is placed in the tank at the same starting location over the acquisition trials, but 'transfer trials' may be later carried out to determine whether place learning can generalise to novel starting locations [see Thinus-Blanc (1996) & Schenk (1998) for further reviews].

4.1.2 VR versions of animal paradigms

Virtual Reality offers the ability to test spatial cognitive abilities of human participants using well researched animal paradigms. Experiments using virtual environments to examine well defined animal paradigms have been carried out by Astur, Ortiz & Sutherland (1998) and also by Jacobs, Laurance & Thomas (1997) and Jacobs, Thomas, Laurance & Nadel (1998) [see also Nadel, Thomas, Laurance & Skelton (1998)]. Morris, Nunn, Abrahams, Feigenbaum & Recce (1999) report using a virtual 'Bin' task, similar to a 9 arm radial maze on human participants, whereas Hamilton & Sutherland (1999) report their findings on a virtual 'blocking' task and demonstrated blocking in humans using distal cues.

Astur et al (1998) used a virtual version of the Morris task to examine place location in a sample of 20 male and 20 female undergraduates. Participants were 'placed' in a virtual room which contained a circular pool with distal cues near the walls of the room but which contained no local / proximal cues. Using a joystick they were asked to navigate the pool and find the hidden platform across 20 trials. Their results showed that place learning in a virtual equivalent of the Morris task was certainly

possible and that males significantly outperformed females using standard measures of performance. Their results suggest that this sex difference was not due to motivational, motor or sensory differences, nor was it due to males increased experience with three-dimensional computer games. Sandstrom, Kaufman & Huettel (1998) showed that male performance where participants had to find a hidden platform dropped in comparison to female performance when geometric cues were removed in a VR environment. This suggests that males and females may behave differently when using proximal, distal and geometric cues.

Jacobs et al (1997) have carried out a number of experiments which also examined human performance in a Morris based task. They wanted to see whether presence of proximal cues prevents learning about the associations between distal ones in a virtual arena as well as looking at the effects of cue removal and rearrangement. Their computer generated environment consisted of a circular arena situated in a square room with 4 surrounding walls, each with different patterns representing distal cues. In their first study, participants were 'teleported' from a practice room to randomised start locations within the test environment and asked to navigate to find the invisible platform. An audible beep was produced by the computer when they crossed over the invisible target. In a probe trial, their results suggested that human participants spent more time in the correct target quadrant than in the others, implying that place location information was learnt and stored within a VR Morris task equivalent. A second experiment showed that when proximal cues were also present within the navigable space they did not 'overshadow' the learning of the distal cue configuration. A third study (10 acquisition trials followed by 3 transfer trials and a probe trial) confirmed that those participants who learnt the location of the invisible target could generalise the position from any start point. The participants' acquisition behaviour

was however different from that observed in the first two experiments. This series of studies showed that spatial information can be learnt within a virtual environment despite the lack of vestibular and motor information derived from traversing real space. Such information is therefore not a requisite of successful place location.

In a further three experiments, Jacobs et al (1998) continued to use VR to explore the importance of distal cues in place learning as purported by cognitive map theory [O'Keefe & Nadel (1978)]. Mapping theory argues that relationships amongst environmental cues are important in forming accurate cognitive maps and that place learning will be disrupted if these relationships are altered.

Jacobs et al's subsequent study looked at the effects of removing distal cues on performance in the computer generated arena. When cues were removed from one, two or even three of the distal walls, place finding was not really disrupted. Cognitive mapping theory predicted this, and also predicted that when all distal cues were removed performance would suffer, which was found to be the case. However performance was not completely destroyed, which suggests that although the relationships between distal cues in an environment may be important, they are not the sole method of solving search tasks of this nature.

The spatial relationships of distal cues can be disrupted by transposition as opposed to cue rotation. A further study by the above research group involved swapping two walls around in the arena and also relocating three walls. Such transpositions significantly effected performance, with participants needing more time to find the target location during the transposition trials. This result has also been shown to be the case in animal maze studies such as the study undertaken by Suzuki, Augerinos & Black (1980) in which rotation of distal cues in an eight arm radial maze did not effect performance, whereas the rearrangement of the relative positions of landmarks did.

Proximal cue transposition has also been shown to effect animal performance in the radial maze, whereas complete removal of proximal cues or cue rotation did not seriously effect the rat's search strategy [Vollmer-Conna & Lemon (1998)]. Williams, Barnett & Meck (1990) have also demonstrated that rats perform worse in a radial maze when room geometry is altered. Such research backs up the idea that both proximal and distal cues can be used in place searching behaviour, but that the more stable distal cues are used preferentially. According to Foreman & Ermakova (1998) "...when intramaze and extramaze cues are compounded, extramaze cues take precedence." (p. 100).

A number of studies devised by Hanspeter Mallot [see Mallot, Gillner, van Veen & Bulthoff (1998), Gillner & Mallot (1998), Mallot & Gillner (2000) and Steck & Mallot (2000)] have investigated the use of local and global information whilst navigating a virtual environment called 'Hexatown'. Hexatown consists of a hexagonal array of seven places, each with 3 roads leading to and from them. Each place is surrounded by three local cues (landmarks) in the form of distinguishable buildings, which are each separated by 120 degrees angle [see fig 2a, p. 452 of Mallot, Gillner, van Veen & Bulthoff (1998) for an overhead view of the hexagonal array]. This leads to a possibility of 21 views throughout the environment; however each place is partially surrounded by a virtual hedge, resulting in visually isolated locations, that is, only one place can be seen at any one time. Movement from place to place is controlled by the computer which reduces the cognitive demands of learning to control navigation within the environment. At each viewpoint a number of possible movement decisions could be made that are controlled by the left, right and middle mouse buttons. Left and right buttons controlled rotation of the viewpoint by 60

degrees anticlockwise and 60 degrees clockwise, respectively. The middle button initiated movement to another place if the current view faces a road.

In one study, Gillner et al (1998) [see also Mallot et al (1998)] tested route, distance and configurational knowledge using their Hexatown environment. They focused on local landmark (local cues) use by including only localised cues and excluding informative global landmarks (distal cues). A mountain range surrounded the Hexatown environment formed by a repetition of a 20 degree segment preventing it from being used as a global landmark]. The use of VR also allowed visual input to be isolated from proprioceptive and vestibular information that was absent, and so focused purely on visual cue use to aid way-finding. The experimenters manipulated the availability of visual local landmarks (buildings) across 4 conditions, which included changing the light condition (bright vs. dark), hedge occlusion and spacing of the landmarks. This led to varying levels of visibility of the environment (i.e. different local view information). Their main findings suggested that spatial relationships were learnt, even in conditions where the degree of visual information was restricted. When information was restricted, this was observed by an increase in errors as the level of visual information decreased. Configuration knowledge was acquired even when only local information was present, suggesting that local or proximal cues are sufficient to find ones way around an environment. Gillner et al (1998) refer to this as ‘view-based’ learning and point out that their results neither support nor refute the integration of such local views into a representation of space.

Mallot & Gillner (2000) investigated recognition-triggered responses in the Hexatown environment. A recognition-triggered response is the recognition of a local view or of a place stored in memory along with an associated action e.g. recognising that you are facing a church and have to turn 90 degrees to head towards another location. Mallot

et al (2000) examined whether the trigger is a local view or a place, defined as a configuration of landmarks. After training participants on a chain of recognition-triggered responses (a route), the authors exchanged the positions of local landmarks (proximal cues). By exchanging landmarks either within a place or between different places 4 individual hypotheses were examined. They concluded, "...local views and objects are recognised individually and that the associated directions are combined in a voting scheme." (p. 43). In their second experiment, landmarks, which were again buildings, were arranged in a different pattern to account for any effect of salience and the results mirrored their original findings.

A third study, by Steck et al (2000), focused more directly on the role of global and local landmarks in navigation of virtual spaces. Unlike the previous experiments using Hexatown, this time the environment had additional global landmarks (distal cues) which surrounded the seven locations, providing a global frame of reference that is insensitive to small distance alterations. Global landmarks included a city skyline, a mountain range and a television aerial tower that could all be seen in the distance, whereas local landmarks were buildings and other objects such as a phone-box. To help create additional feelings of presence, the virtual environment was displayed in front of participants on a 180 degree projection screen developed by Veen, Distler, Braun & Bulthoff (1998), cited in Steck et al (2000). The authors hypothesise that reliance on landmarks can take a number of forms. Participants may use solely local landmarks, global landmarks or a combination of both to way-find in virtual environments. Participants may also alternate strategies according to the nature of the task, suggesting a flexible navigation system. They investigated these possibilities by using a cue-conflict experiment in which changing the arrangements of global and local cues would predict different movement decisions.

Their first experiment used a cue conflict condition by rotating the three local cues by 120 degrees clockwise. Reliance on local cues would therefore result in an opposite movement decision to that of the global landmarks, thus highlighting which strategy participants are adopting. The aim of the participants was to learn the route from one location to another ('home' and 'office') by navigating along the adjoining roads. Two training phases taught the participant to learn the route from 'home' to 'office' (and vice versa) and also to find the goal from a novel location. The training phases were terminated when this procedure was completed with no errors. The test phase had two conditions, control condition (no cues rotated) and cue-conflict condition. The general conclusion from this experiment was that both local and global cues are used to help navigate successfully and that dependence on each seems to vary across individuals. Some participants even used both strategies, alternating between them depending on the nature of the goal and where they were in the environment. Differences of strategy, according to location within the environment, were explained in terms of cue salience, whereas differences according to goal were explained in terms of cue constellations. Finally Steck et al (2000) report that over 50% of participants failed to notice the changes to the global landmarks, suggesting no conscious awareness of the combination of global and local cue arrangements.

A second experiment from this paper further investigated cue manipulations, but this time by removing either global or local cues completely. This was achieved by changing the environmental lighting conditions ('night' versus 'dawn') that resulted in global and local landmarks respectively being invisible. A control lighting condition in which both global; and local cues could be seen was also used. The results suggested that, even for those participants who tended to use one dominant

landmark strategy in the first experiment, information was stored in memory for both types of cues and way-finding was still possible.

The following experiments use a novel virtual reality environment to examine human performance in a human radial maze equivalent. The use of VR allows the manipulation of proximal and distal cues to occur seamlessly [Foreman & Wilson (1995)] with no long inter-condition pauses which might otherwise affect short-term memory storage. This study looks at *both* distal and proximal cue usage in a multiple goal paradigm, with the aim of showing differential cue use in a human radial maze analogue.

4.2 A Radial Search Paradigm Demonstrating Cue Preference (Experiment 1)

4.2.1 Method

Participants:

48 students (22 males and 26 females), all undergraduate psychologists, were tested. Mean age for males was 20.59 (SD = 4.35) and 17.31 (SD = 1.60) for females. The mean age for the whole sample was 18.81 (SD = 3.54).

All participants had normal or corrected-to-normal vision (glasses or contact lenses).

Design:

A repeated measures design was implemented, with participants being tested across all 3 conditions (2 experimental manipulations plus a control). The ordering of these 3 conditions was fully counterbalanced to control for practice/order effects. The independent variable was *Cue Condition (3 levels)* and the dependent variable was the frequency of correct choices of previously unvisited targets (*frequency correct*).

Frequency correct was always between 4 and 8, as the first four visits to locations were always correct (see procedure). Also, the total number of visits to targets performed by the participants in order to select all four previously unchosen targets (during choice phase B, see Fig 1, p. 155) was recorded. If all 4 remaining targets hadn't been visited by the eighth choice, the value was recorded as $8 + n$ (where n was the number of remaining unvisited targets). This is referred to as '*number of visits*' and ranges from 4 to 12 as a cut off was imposed (see procedure).

Participant's gender was also treated as an independent variable during the statistical analysis.

Apparatus:

A three-dimensional VR environment was constructed using the Superscape software described in Chapter 1. The environment consisted of a circle of orange and white traffic cones which formed the circumference of an open arena. The environment mimicked an outdoor scene, with a blue sky and green ground, meeting at a horizon. Within the circular area were 2 types of object, all randomly positioned. The two types of objects within the arena were *choice targets* and *proximal cues*. The choice targets consisted of 8 yellow hexagonal solids and the proximal cues were 6 randomly chosen objects from a standard 3D clip-art gallery within the Superscape software package. The proximal cue objects are listed in Table 1 below.

Around the perimeter of the circle of cones were 6 *distal cue* objects, which were also randomly assigned to locations around the outside of the choice arena. The distal cue objects are also listed in Table 1 below.

P.T.O.

Proximal Cue Objects	Distal Cue Objects
An old gramophone	A bunk bed
A park bench/chair	A potted plant
A fizzy drinks can	A TV/video display screen
A large striped cube/box of drawers ²	A triangular roadworks sign
A toaster	A green bottle
A candle	A wardrobe

Table 1 - Proximal and Distal Cue distribution in the 3D environment

At the bottom right hand corner of the viewing screen, a small display window was present (approx. 1 x 1 cms) which updated to reflect a target number code (displayed in red) whenever a target object was clicked on with the left mouse button. Figures 3, 4 and 5 in the Appendix (Section 4.5) show screen-shots from the environment.

Movement in the environment was controlled by the cursor keys **↑**, **↓**, **←** and **→** (forward, backwards, rotate left and rotate right). This mobile human viewpoint was activated by pressing the F6 function key. An overhead view of the environment, highlighting its circular structure, was activated by pressing the F2 key. This overhead view was not detailed enough to give any spatial information, as individual cues could not be distinguished from one another.

Two other versions of the environment were created. The first was the same as the default control environment (described above), but with all the distal cues removed

² This object was ambiguous and was at times referred to by participants as a “box of drawers”.

and the second was the same as the control environment but with all the proximal cues removed. Both of these manipulated environments could be loaded from the control environment by pressing the “Shift-I” or “Shift-E” key combinations, respectively. The experiment was run on a Pentium class personal computer and the environment was displayed on a 21 inch monitor.

Procedure:

Participants were initially acquainted with VR environments through navigating and exploring a separate room environment, which allowed for practice navigation via the keyboard and object selection using the mouse.

For the main experiment, participants were placed in front of the computer, at a suitable viewing distance from the monitor. They were introduced to the default control environment (i.e. all cues present) and shown a circle of traffic cones surrounding a circular arena containing 8 targets (yellow hexagonal solids) and 6 random objects. Their attention was also drawn to the 6 objects on the outside of the circle. Prior to the experimental trials, an overhead view of the environment was briefly shown to the participants to help emphasise the general environmental structure.

Participants were then asked to navigate within the circular arena using the cursor keys and to select four of the yellow targets, by approaching them one at a time and then clicking on the target with the left mouse button (i.e. moving the mouse arrow cursor over the target and depressing the left mouse button). They were invited to try and remember the locations of the selected four targets. If participants made an error during the initial four choices, that is they revisited an already chosen target, then the error was pointed out and they were asked to choose again until they had identified 4

distinct targets. Participants were deterred from making simple algorithmic choices, such as choosing adjacent targets, by using a randomly distributed, asymmetric arrangements of targets. After choosing four targets, the experimenter manipulated the cue arrangements by pressing the appropriate control keys on the keyboard (see apparatus above). This resulted in either the proximal cues being removed, the distal cues being removed, or the default environment (containing all cues) being reloaded. After this cue manipulation, the participants were asked to navigate towards the remaining four previously *unchosen* targets and to select them with the mouse cursor. They were asked to try not to make any errors, but that they would be told if they had made one, and the nature of the error. Errors at this stage were of two types;

1. *Participants chose one of the four targets that they had previously chosen during the (the equivalent of returning to a previously baited arm in the animal radial maze) initial choice phase A (see Figure 1 below), or*
2. *Participants returned to an already chosen target which they had chosen during this second choice phase B (see Figure 1 below).*

Choice phase A					Choice phase B							
1	2	3	4	⊗	5	6	7	8	[9	10	11	12]
⊗ = cue manipulation point												

Figure 1 – Structure of choices

If, by choice 12, participants had still not visited the remaining 4 targets, then they were asked to stop. In a completely error free trial, the participants were expected to use choices 1-4 (black, in figure 1) to correctly visit four distinct targets and then, after the cue manipulation, to use choices 5-8 (blue, in figure 1) to correctly identify the targets which were unvisited in phase A.

Target choices were recorded by the experimenter by means of the identifying target code at the bottom of the screen. Had participants noticed this code (most of whom did not) they would have gained no advantage in carrying out the required task.

The participants were each exposed to three trials in a random order, one for each of the 3 Cue Conditions (both proximal/distal cues present, proximal cues present, distal cues present).

After the main experiment participants were asked to recall as many of the cue objects as they could, in any order. They were also asked what strategies they had used to remember the visited and unvisited locations and finally they were asked if they had noticed any changes in the environment between choice phases A and B.

4.2.2 Results

The *frequency correct* (number of correct visits in choices 1-8) data was analysed using a 2 WAY (3 X 2, Cue Condition by Sex) mixed ANOVA. A significant main effect for Cue Condition was observed [$F(2,92) = 6.87$; $p < 0.05$]. No significant differences between males and females were found [$F(1,46) = 0.23$; $p > 0.05$]. The interaction of Cue Condition & Sex was also found to be non-significant [$F(2,92) = 0.60$; $p > 0.05$]. Figure 6 (see appendix) shows the trend in scores across all three cue conditions for all participants. Although a trend can be seen in scores in Figure 6, the follow up planned contrasts across the 3 levels of Cue Condition showed that only the conditions in which both proximal & distal cues remained ($\bar{X} = 7.17$) and in which the proximal cues only remained ($\bar{X} = 6.54$) differed significantly [$F(1,46) = 12.54$; $p < 0.01$]. High *frequency correct* represents better performance, with participants performing significantly worse when only proximal cues were present i.e. distal cues are removed from the environment.

The *number of visits* data was analysed next, again using a mixed ANOVA. The main effect for Cue Condition was again significant [$F(2,92) = 3.88$; $p < 0.05$] and no significant effect for Sex was observed [$F(1,46) = 0.25$; $p > 0.05$]. Again no significant interaction effect was present [$F(2,92) = 0.27$; $p > 0.05$]. Figure 7 (see appendix) graphs the data. The planned contrasts again showed that only the conditions in which both proximal & distal cues remained ($\bar{X} = 6.08$) and in which the proximal cues only remained ($\bar{X} = 7.23$) differed significantly [$F(1,46) = 6.95$; $p < 0.01$]. A high *number of visits* represents worse performance. Participants took significantly more choices to obtain all 8 targets (performed worse) when only proximal cues were present compared with both proximal and distal cues being available.

The recall of cues was then analysed. The total number of cues correctly recalled did not differ between males and females [$F(1,46) = 1.98$; $p > 0.05$] and there was no interaction between Sex and Cue Type (Proximal & Distal) [$F(1,46) = 1.30$; $p > 0.05$]. However, there was a significant main effect for Cue Type, with distal cues ($\bar{X} = 4.50$) being recalled better than the proximal ones ($\bar{X} = 3.27$), [$F(1,46) = 51.1$; $p < 0.01$]. Figure 8 (see appendix) graphs these findings.

4.2.3 Discussion

The results from Experiment 1 suggest there is no difference in performance on both measures between male and female participants. This contradicts the findings of Astur et al (1998) who observed a reliable sex difference on a virtual reality version of the Morris water maze. Their results suggested that males performed better than females when identifying the location of a hidden target, however this was not found to be the case in this virtual task. However, their computer environment did not incorporate

proximal cues and also had only one target location, so it could be argued that the additional complexity of this particular task masked any observable sex differences. In terms of overall recall of the environmental cues, again no sex differences were apparent, with males recalling as many cues as females.

Despite the lack of observable sex differences the findings with respect to cue presence are promising. The significant main effect for Cue Condition suggests that performance (on both measures) is affected by the presence or absence of proximal and distal cues. Performance was best when both types of cues were present in the environment and dropped significantly when the distal cues were removed. Memory for distal cues was also seen to be significantly better than for proximal ones, suggesting that they are used more in finding the way around an environment. Participants' performance did not drop to zero when either proximal or distal cues were removed and both types of cues were recalled. This suggests that participants have access to both types of cue information within a virtual environment, as supported by the findings of Steck et al (2000).

Other limitations of this study could have occurred as a result of the within subjects (repeated measures) design. Some participants may have been aware of the deletion of one group of cues in a trial and this may have alerted them to the experimental design and caused them to adopt a different strategy for the subsequent trial(s). This may account for the lack of an observed difference between the two conditions in which either proximal or distal cues were removed. Only one trial was given in which a "normal" search strategy could be developed and this may not have allowed enough time for an individual's spatial strategy to be firmly formed.

It was therefore decided to run a second study which expanded upon the first and was designed to be a between subjects (independent groups) design. A longer training

period was given and 2 additional Cue Conditions were added. The additional Cue Conditions involved a more subtle approach to disrupt participants' strategies. Either the positions of the proximal cues or the distal cues were rearranged, but not deleted. This was expected to cause disruption of place learning (as suggested by map theory [O'Keefe & Nadel (1978)]) particularly with respect to distal cues, as observed by Jacobs et al (1998).

4.3 A Radial Search Paradigm Demonstrating Cue Preference (Experiment 2)

4.3.1 Method

Participants:

48 undergraduate students (24 males and 24 females) from the Psychology department at the University of Leicester were tested. Mean age was 18.75 for males ($SD = 2.13$) and 18.83 ($SD = 1.81$) for females. The mean age for the whole sample was 18.79 ($SD = 1.96$).

Participants had no previous experience using VR. All participants had normal or corrected-to-normal vision (glasses or contact lenses).

Design:

Unlike experiment 1, an independent measures / between subjects design was used, with 12 participants (6 males and 6 females) being randomly assigned to each of the four cue conditions.

The independent and dependent variables were the same as for experiment 1, except that the IV (Cue Condition) had 4 levels (proximal cues only present, distal cues only present, proximal cues rearranged & distal cues rearranged).

Gender was again used as an independent variable in the analysis.

Apparatus:

The apparatus was the same as in experiment 1, with the addition of two environments which could be loaded from the default environment using the Shift-S (distal cue arrangement changed) or the Shift-L (proximal cue arrangement changed) key combinations.

In the new proximal cue condition, two randomly chosen pairs of proximal cues exchanged positions and in the new distal cue condition, two distal cue pairs were exchanged. To clarify, if a chair was in position A and a toaster at position B in the default environment, then in the new environment the chair would be at B and the toaster at A.

Procedure:

The experimental procedure was similar to that of experiment 1, with a few minor differences.

Each participant was initially given five training/control trials, in which no cue changes were made between the 2 choice phases. This was followed by three experimental trials, in which the cue configurations were changed after phase A depending on which of the four Cue Condition groups the participant was assigned to. Trials are summarised in figure 2 (below).

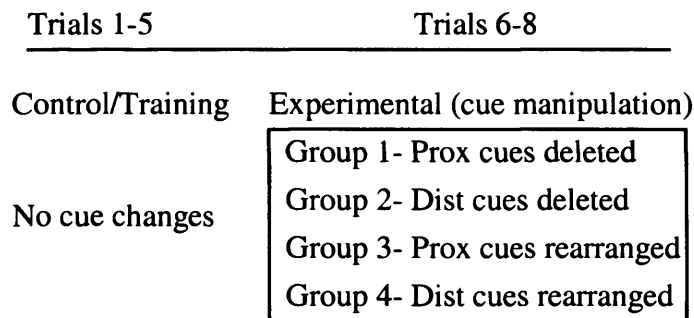


Figure 2- Diagram of trial structure

Performance on each trial was measured as in experiment 1.

4.3.2 Results

Initially statistical analysis was carried out using the data from the five training trials. A 3 WAY [(2 X 4 X 5) Sex X Cue condition X Trial] ANOVA (mixed) was used to perform this analysis. On measures of the number of correct visits to targets across choices 1-8 (*Frequency correct* data), no main effect for Cue Condition was observed, as expected (since there was no real changes between groups until trial 6) [$F(3,40) = 1.90$; $p > 0.05$]. A main effect for Trial was obtained [$F(4,160) = 8.24$; $p < 0.001$ {Trial 1: $\bar{X} = 6.65$ (SD = .84); Trial 5: $\bar{X} = 7.48$ (SD = .77)}] which signified the gradual increase in performance across the training trials. A main effect for sex was also found [$F(1,40) = 4.22$; $p < 0.05$ {Males: $\bar{X} = 7.31$ (SD = .40), Females: $\bar{X} = 7.05$ (SD = .49)}], with males performing better than females during training, however an interaction between sex & trial [$F(4,160) = 3.16$; $p < 0.05$] suggested that although males initially out-performed females, this difference dissipates across training, leading to no significant difference between sexes for trials 4 & 5.

Next the data for trials 6-8, the cue manipulation trials, were analysed (an average across the 3 trials was used as a previous analysis had shown no effect of Trial

[$F(2,80) = 1.27$; $p > 0.05$]). On measures of the number of correct visits to targets across choices 1-8 (*Frequency correct* data), a main effect for Cue Condition was seen [$F(3,40) = 3.30$; $p < 0.05$]. This can be seen in Figure 9 (see appendix).

Post-hoc analysis showed that means differed significantly for the 'distal relocated' ($\bar{X} = 6.5$) and the 'proximal relocated' ($\bar{X} = 7.2$) groups, with participants in the 'proximal relocated' group performing better. None of the other means for the cue condition groups differed significantly. Further post-hoc analysis showed that when proximal cues were manipulated (removed or relocated), performance was better than when distal cues were manipulated [$t(46) = 2.7$; $p < 0.05$ {Prox cues: $\bar{X} = 7.04$ SD = .63, Dist cues: $\bar{X} = 6.57$ SD = .58}]].

Continued analysis highlighted a main effect for Sex, with males performing better than females [$F(1,40) = 3.93$; $p = 0.05$]. There was no interaction effect of Cue Condition by Sex [$F(3,40) = 1.26$; $p > 0.05$].

The *number of visits* data were then analysed in the same way as the score data above (a 2 X 4 X 5 ANOVA). During the training trials, no difference between subsequent cue condition groups was observed on this measure, i.e. no main effect for Cue Condition [$F(3,40) = 1.86$; $p > 0.05$]. An increase in performance across trials was again observed [$F(4,160) = 5.34$; $p < 0.01$, {Trial 1: $\bar{X} = 10.67$ (SD = 1.75); Trial 5: $\bar{X} = 9.15$ (SD = 1.68)}]]. Male participants again outperformed females [$F(1,40) = 8.47$; $p < 0.01$, {Males: $\bar{X} = 9.28$ (SD = .86), Females: $\bar{X} = 10.04$ (SD = .98)}]].

Analysis of test trial data (again using the pooled data across trials 6-8) on this measure revealed no main effect for Cue Condition [$F(3,40) = 1.46$; $p > 0.05$], nor for Sex [$F(1,40) = 2.79$; $p > 0.05$] and no interaction of Cue Condition by Sex [$F(3,40) = 0.84$, $p > 0.05$].

Finally, recall of environmental cues was analysed as in Experiment 1. Participants recalled more distal cues than proximal ones (see Figure 10 in appendix) [Main effect for Cue Type: $F(1,40) = 8.79$; $p < 0.01$]. There was no interaction between Cue Type and Cue Condition [$F(3,40) = 0.19$; $p > 0.05$], however Cue Condition and Sex did interact [$F(3,40) = 5.96$; $p < 0.01$]. Post-hoc comparisons revealed that overall recall of cues was better for males than females in the proximal relocated cue condition [$\bar{X} = 9.0$ (SD = 2.28) versus $\bar{X} = 5.83$ (SD = 1.47), $t(10) = 2.86$; $p < 0.05$], and that in the distal relocated cue condition recall was better for females than males [$\bar{X} = 9.0$ (SD = 2.10) versus $\bar{X} = 6.34$ (SD = 1.51), $t(10) = -2.53$; $p < 0.05$].

4.4 Main Discussion

These two experiments investigated the use of distal and proximal cues in solving a multiple goal task, which is in essence a human radial maze analogue. Both experiments also looked at gender differences in performance on this task.

The results of the second experiment suggest differential use of cue strategies as found in the first experiment, but also suggest possible sex differences which Experiment 1 failed to uncover. During the acquisition training trials in Experiment 2, male participants out-performed the female participants agreeing with the findings of Astur et al (1998). This finding was supported by the data from the cue manipulation trials which also suggested that males were better at the task. This may well be indicative of a male flexibility with respect to cue strategy use. The lack of any observable sex difference in Experiment 1 causes concern and may be as a result of the difference in design structure of the two experiments. The second experiment also allowed additional time for strategies to be developed and may have led to more observable sex differences. As is often the case in spatial experiments that have

observed gender effects, the findings are mixed with respect to male and female performance.

A gradual increase in performance was evident over the initial training trials, which was indicative of a typical learning period over trials. With respect to the recall of environmental cues, distal cues were once again better recalled in Experiment 2, with males having better recall in the proximal cues relocated condition, and females recalling having better recall in the distal cues relocated condition. However, a female preference for distal cue use was not observed, contrary to the findings of Sandstrom et al (1998).

The results presented in Figure 9 (see appendix) suggest that performance varies according to the Cue Condition presented. Both types of cue were present in the relocation conditions, however the spatial arrangement of distal or proximal cues was disrupted. Performance of participants when proximal cues were relocated was the highest, paralleling the scores when both cues types were present in Experiment 1. When cues were relocated, as opposed to being removed completely, a significant effect on performance was observed, with better performance in the proximal relocated condition compared to the distal relocated condition. These results suggest that strategies may vary when distal and proximal cues are relocated and that these strategies may be different for cue removal. Overall manipulation of distal cues led to worse performance by participants, suggesting that distal cue strategies are used more predominantly in place location. Relocation of distal cues led to the worse performance across the 4 cue conditions, as was expected according to O'Keefe & Nadel (1978). However, disruption of more localised cues did not seem to effect performance, which strongly suggests that distal cues were being used more predominantly than proximal ones. The fact that performance was also higher in the

'proximal relocated' condition infers that participants were able to use local cues in addition to distal ones. These results are in agreement with Jacobs et al's (1998) who showed that even when proximal cues are present, they do not overshadow the use of distal cue configurations. However these results do not infer a specific strategy that our participants used to perform this task. Most reported associating specific cues with a particular target but did not differentiate between proximal and distal cues per-se.

Even when cue conditions within the virtual environment were manipulated, most participants were still able to distinguish between chosen and un-chosen target locations. It is therefore clear that spatial information can be learnt from a virtual environment, agreeing with the research literature [Morris et al (1999), Astur et al (1998), Jacobs et al (1997) and Jacobs et al (1998)].

It is also clear that complete immersion is not necessary in VR testing paradigms in order for spatial information to be acquired and stored in memory. This is useful as the implication arises that VR paradigms of this nature can be used to examine spatial processing in clinical patient groups, for whom complete immersion might be ethically unsound. The results of these studies also show that vestibular and kinaesthetic information that would normally be present in a *real* human radial maze task is not required to form a spatial map of the environment, however this does not rule out a role for these additional physiological cues. Nadel et al (1998) showed that even virtual navigation within a computer generated arena is not necessary to construct a map of the position of a hidden target. Other factors which may deter learning in virtual environments do not seem to have prevented learning in this case [see Rose & Foreman (1999)].

Although it is not believed that the cue identifying number shown at the bottom of the screen could have easily been used to aid performance in this task, an improvement to

these experiments might be to record participant responses in a more elaborate manner. This would require more complex programming but is certainly possible for a qualified computer programmer to perform. This would allow data collection to be completely automated and hence reduce the possibility of human error. Other variations on this paradigm might involve having a sub-set of the yellow hexagons as targets. This would be the equivalent of having only a number of baited arms in a radial maze. Another possibility is the relocation of pairs of proximal and distal cues, that is, swapping the position of a distal cue with one of the proximal ones. This may help determine if cue salience is an influencing factor. Removal of all cues is an alternative possibility, however a pilot study suggested that having no cues seriously disrupted performance.

In conclusion these experiments have shown that cue use strategies in a multiple goal task can be examined using the highly controllable environments that virtual reality technology provides. Virtual reality testing environments offer the ability to manipulate local and global cues as a means of helping to isolate the importance of these types of landmarks. There seems to be evidence that distal cues may be used preferentially in these types of tasks as in accordance with Nadel et al (1998) who suggested that distal cues may be more important in 'mapping' the environment. The findings also suggest that males perform better than females on test trials as in agreement with the work of Astur et al (1998). However such sex differences may not always be consistent as observed from the two experiments.

4.5 Appendix

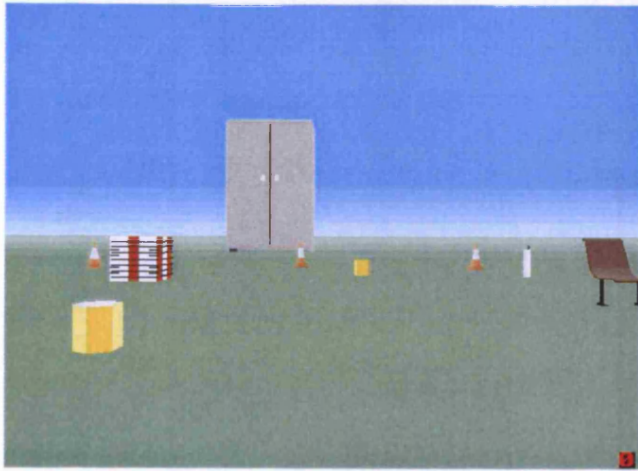


Figure 3- Screen shot of environment



Figure 4 – Alternative screen shot of environment

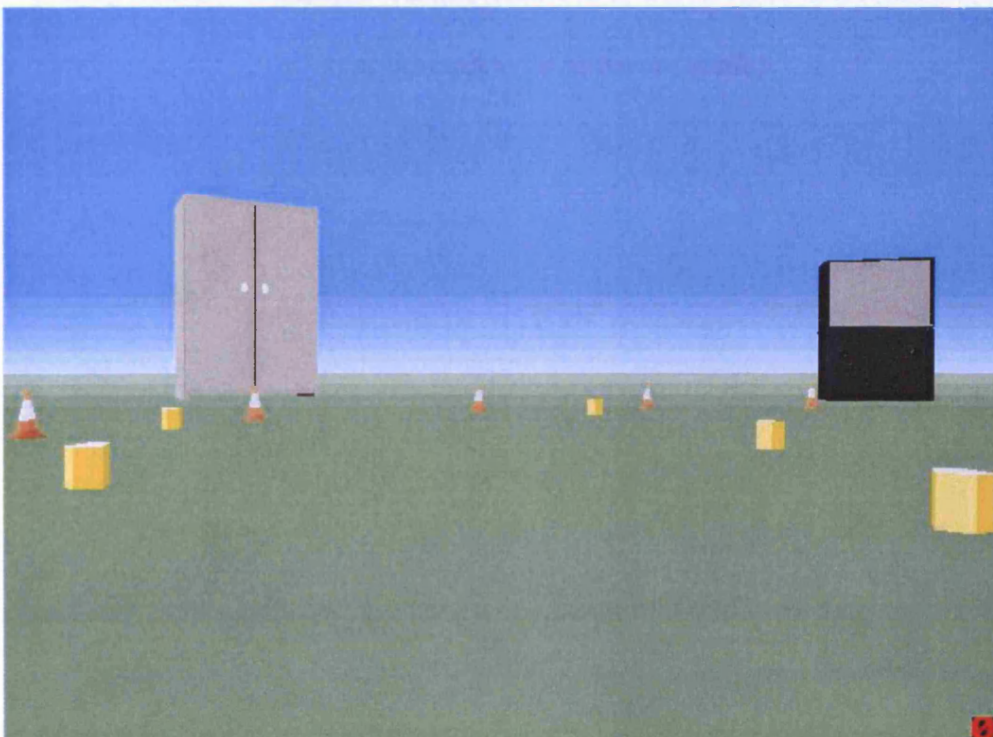


Figure 5- Environment with no proximal cues

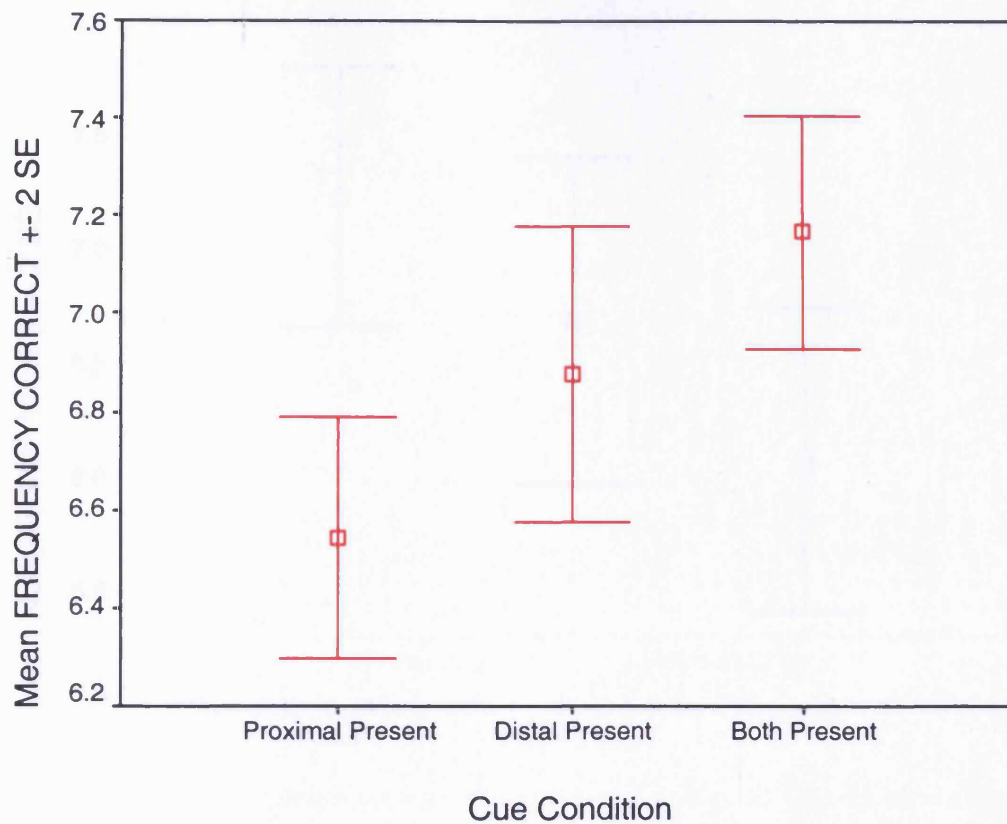


Figure 6 – Graph showing mean *frequency correct* across the 3 cue condition groups. Whiskers represent standard errors.

(FREQUENCY CORRECT ranges from 4 to 8, with a score of 8 reflecting perfect performance i.e no errors made)

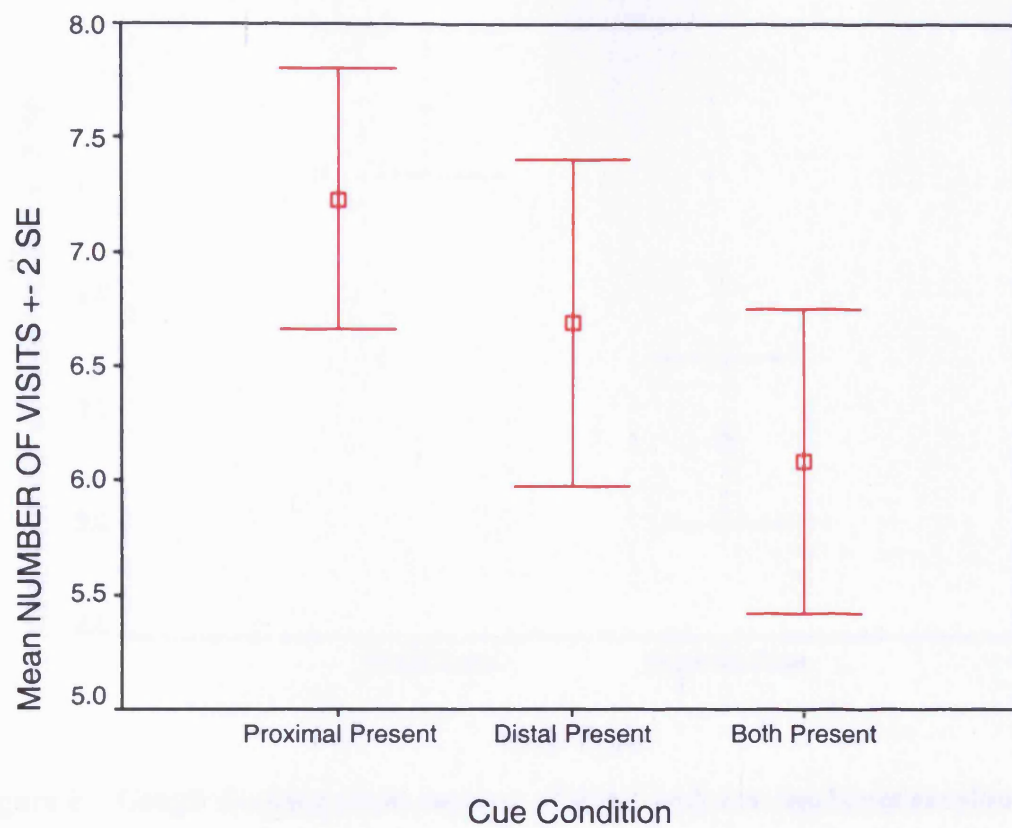


Figure 7 - Graph showing mean ‘*number of visits*’ across the 3 cue condition groups. Whiskers represent standard errors
(*NUMBER OF VISITS* ranges from 4 to 12, with a score of 4 reflecting perfect performance i.e no errors made)

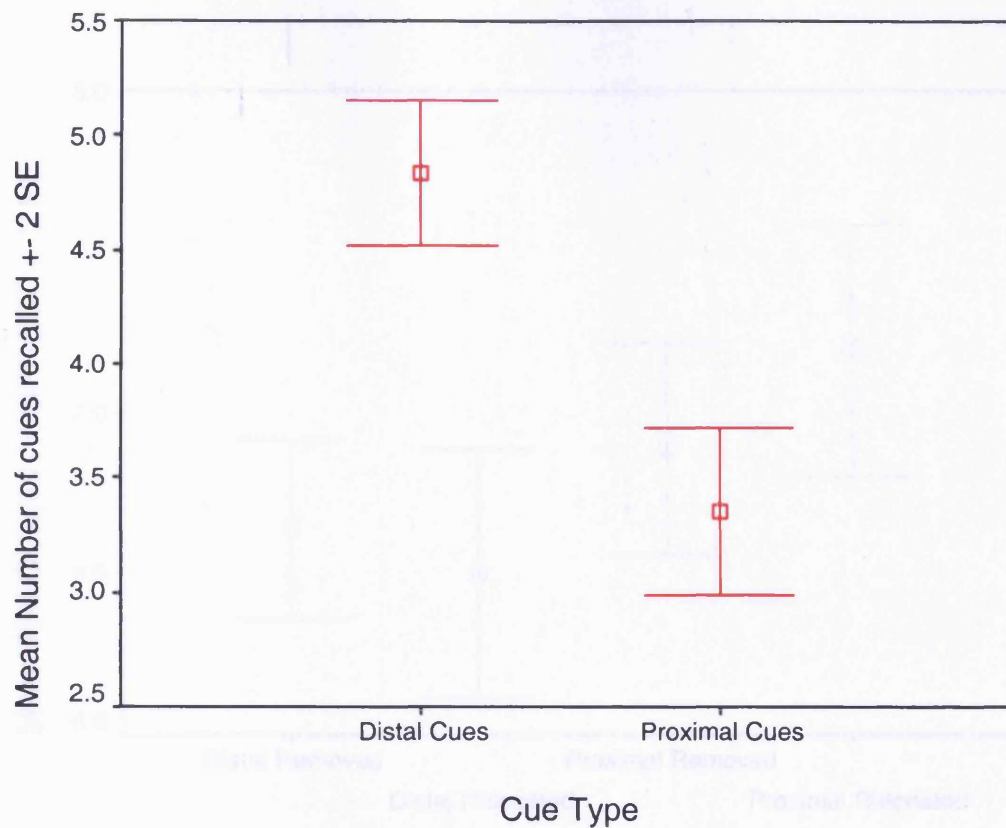


Figure 8 – Graph showing mean number of distal and proximal cues recalled by participants in Experiment 1.

Whiskers represent standard errors

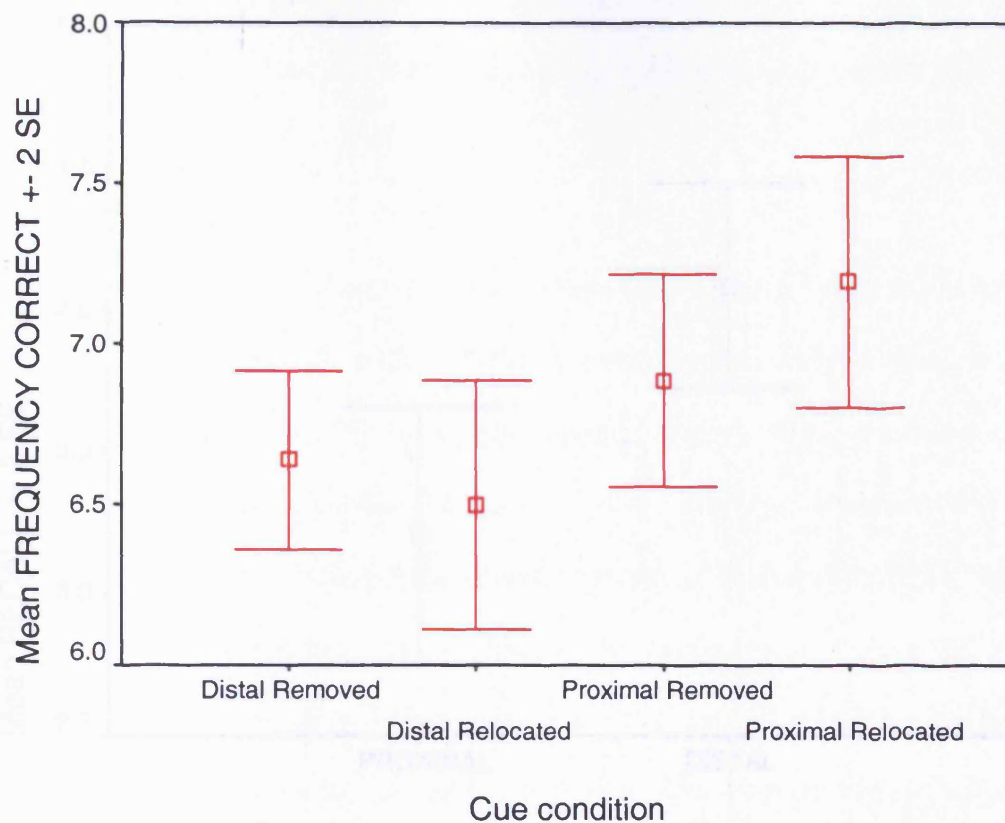


Figure 9 – Graph showing mean *frequency correct* across the 4 cue condition groups in Experiment 2 (Trials 6-8 pooled).

Whiskers represent standard errors

(FREQUENCY CORRECT ranges from 4 to 8, with a score of 8 reflecting perfect performance i.e no errors made)

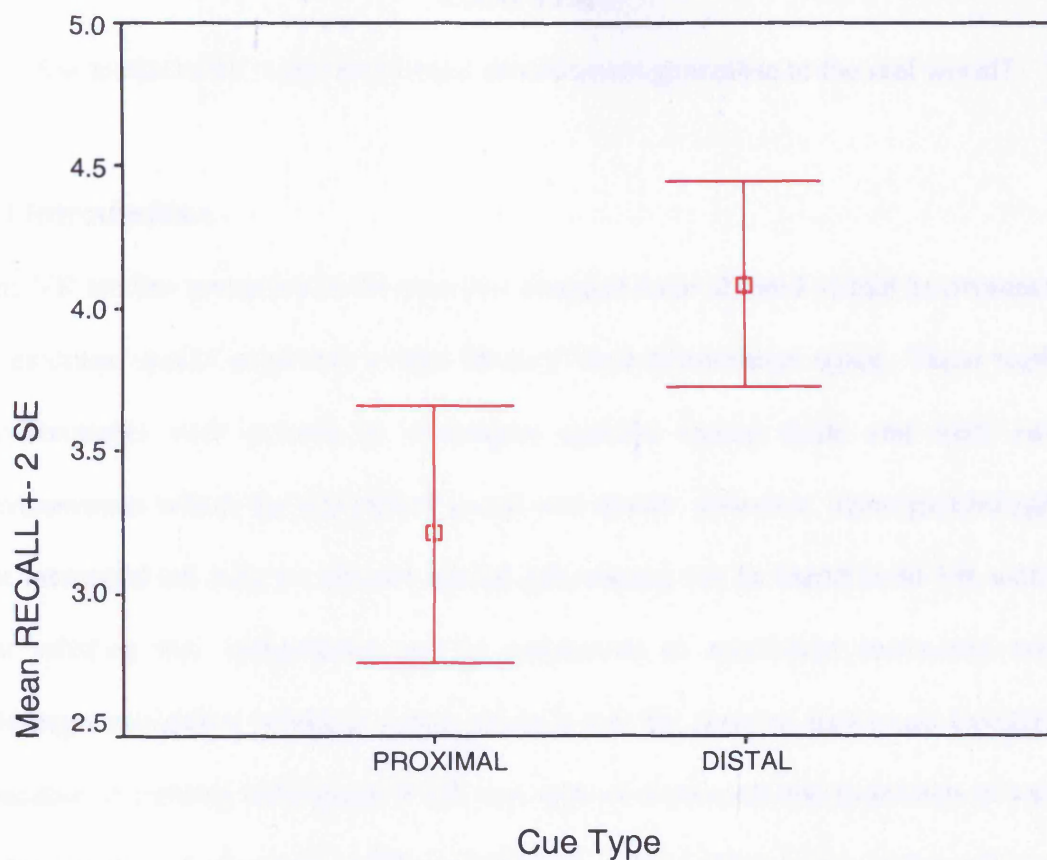


Figure 10 – Graph showing mean number of proximal and distal cues recalled by participants in Experiment 2.

Whiskers represent standard errors

CHAPTER 5

Do spatial skills learnt in a virtual environment generalise to the real world?

5.1 Introduction

The VR studies presented in the previous chapters have all used virtual environments to examine spatial cognition within illusory three-dimensional space. These testing environments were created to investigate specific spatial skills and were novel environments which did not reflect actual real spaces. However, some psychologists are interested not only in whether spatial information can be learnt from VR worlds, but whether this information can be transferred to equivalent real-world tasks. Although navigation within a virtual space is *not* the same as real-space navigation [because of existing limitations of VR, e.g. type of movement and restriction of visual field; see Rose & Foreman (1999) and Wilson (1997)] if behaviour in the real world parallels behaviour in a virtual environment then virtual reality offers psychologists a way of assessing spatial behaviour in environments that are based upon existing real spaces. This is particularly useful for examining spatial behaviour of large samples of participants in a specific environment as well as for training purposes. This chapter focuses on replicating an existing spatial testing environment, that of the Kiel Locomotor Maze, then determining if behaviour in the virtual version of the maze is transferred to the real one. If this is found to be the case, then this static test paradigm can be used in virtual form, making it more accessible than at present.

A number of studies have looked at direct transfer of skills from a virtual environment to a real one. Wilson, Foreman & Tlauka (1997) had able-bodied children navigate either a real 3 floor building or a desktop VR simulation of the environment. Both groups were then given a number of spatial tasks including a map drawing task and a

pointing task within the real environment and compared with a control group who had not received any experience of the building (either virtual or real). Their results showed that those participants who had had direct navigational experience of the building performed best on the spatial tests; however the VR groups' performance were very similar to those with direct experience and significantly better than a control group who had had neither real nor VR training and asked to make reasoned guesses. It was therefore concluded that spatial knowledge was transferred from virtual to real. An earlier study by some researchers [Wilson, Foreman & Tlauka (1996)] looked at transfer to the same environment but using physically disabled children. The test was presented as a game involving escaping from a fire and again showed transfer of route knowledge. A similar study was run by Stanton, Foreman & Wilson (under review) which supported transfer of spatial skills from a virtual simulation of a school to the real environment. Additional studies investigating transfer of training were discussed in section 2.4.3.3.

The Kiel locomotor maze is a spatial testing environment which assimilates elements from both the radial maze and the water maze paradigms as described in Chapter 4 (Section 4.1.1). The Kiel team wanted to develop an experimental paradigm that could be used on humans and which would assess spatial behaviour in a similar manner as the radial arm maze and water maze did in animals. This required an experimental set-up which would allow control of intra- and extramaze cues, which differentiated between place and landmark strategies and was conceptually equivalent to animal studies. These requirements, along with others [see Leplow, Holl, Zeng & Mehdorn (1998)] led to the development of a locomotor maze incorporating features from both the water maze and the radial maze experiments. The original version was designed to test cue and place learning strategies in adults, but has since been re-developed to

assess children's spatial behaviour [Lehnung, Leplow, Friege, Herzog, Mehdorn & Ferstl (1998), Lehnung, Herzog, Dierks, Ferstl, Mehdorn & Leplow (1998), Lehnung, Leplow, Herzog, Friege, Mehdorn & Ferstl (in preparation)].

Leplow, Holl, Zeng & Mehdorn (1998) used the Kiel Maze to examine cue dependent orientation in adults and to dissociate between different classes of memory in a search task. Using various cue manipulations, results suggested that distal cue information was important for effective place learning and that Parkinson's disease patients showed an increase in working memory errors compared to controls. Research is continuing by the Kiel team to differentiate different strategies in clinical patient samples.

Lehnung, Leplow et al (1998) have used the Kiel maze to trace the development of spatial strategies in children aged between 5 and 10 years. A number of tasks involving cue rotation, cue deletion and response rotation [see Figure 3, p. 471 in Lehnung, Leplow et al (1998)] were used to determine the type of orientation strategy that was being implemented. The results showed that younger children (5 year olds) stick to using proximal cues in a cue-bound strategy, where as by the age of 10, children had developed the ability to use distal cues for orientation in a place strategy. The middle group of children used both methods, suggesting a gradual developmental shift from one strategy to the other. In addition to the studies looking at child development and adult spatial skills, Lehnung, Leplow, Dierks, Herzog, Grabs, Benz, Ritz, Johnk, Mehdorn & Ferstl (submitted) have looked at spatial behaviour in children with closed head injuries in the locomotor maze. They found that children with CHI showed larger inter-response intervals on the maze and some were simply unable to learn the cue configurations.

A computer version of the Kiel maze ['search through' task] has been developed and used to test childrens spatial cognition [Lehnung, Leplow, Herzog et al (submitted)], however in this case the environment was a two-dimensional version which allowed all floor targets, proximal and distal cues to be seen simultaneously. The development of a VR maze, as presented in this experiment, overcomes these obstacles and allows a more realistic test in a 'three-dimensional' space, simulating movement and creates a feeling of 'presence'. The VR version of the maze is therefore more comparable to the real maze than the 2-D 'search through' task.

Another element of spatial cognition investigated in this study was that of possible differences between active and passive learning. Active exploration involves both physical activity and psychological activity [Wilson, Foreman, Gillett & Stanton (1997), Wilson (1997)]. A study by Peruch, Vercher & Guathier (1995) highlighted differences between active and passive behaviour in a virtual environment, however further studies by Wilson et al (1997) and Wilson (1999) failed to find any advantage for active participants. The current study looked at a non-locomotor (passive) and a locomotor (active) group in the real maze to determine any active/passive differences in performance.

The Kiel locomotor maze has a number of useful applications for exploring spatial behaviour, however one of its limitations is that it is a fixed location maze that cannot be moved from place to place. This means that participants have to be transported to it, which results in extra expense and inconvenience. In collaboration with Kiel University psychology department, it was decided to construct a virtual simulation of the locomotor maze, which worked in a similar way, but which was transported anywhere testing needed to be carried out. This portability offers a great advantage particularly for the testing of clinical patients. There is also the advantage that whole-

body movement is unnecessary when carrying out the task, as 'movement' is controlled via a joystick or keyboard interface.

This study aims to explore the quality of transfer of spatial information from a virtual to a real experimental testing environment, whilst also examining any sex differences and active-passive differences.

5.2 Transfer of spatial skills from a virtual to a real locomotor maze

5.2.1 Method

Participants:

72 children (36 males & 36 females) from various schools in Kiel, Northern Germany, were recruited and tested in this study. All were 11 years of age with normal or corrected-to-normal vision. None of the children had had prior experience with virtual reality experiments or with the Kiel locomotor maze.

Design:

A completely between subjects design was used. Two independent variables of Training Condition (3 levels: No VR training, Correct VR training & Incorrect VR training) and Exploration Type (2 levels: Active exploration & Passive non-locomotor exploration) were analysed. 24 participants were randomly assigned to each of the 3 training conditions, 12 being given active exploration and 12 passive exploration. Of the 6 sub-groups, each contained 6 males and 6 females.

Apparatus:

This experiment used the Kiel Locomotor Maze and also a virtual reality maze, built to replicate the real maze as accurately as possible. Each will be described in turn:

(1) Kiel Locomotor Maze

The Kiel locomotor maze is housed in the physiology department in the university of Kiel in Germany. It is a non-mobile circular arena which was designed to test humans on spatial paradigms. The maze was constructed from a raised, circular, wooden platform (approx. 20 cm in height), 3.6 m in diameter. This platform was completely surrounded in a black curtain (to a height of approx. 5 m), enclosing the platform, creating a circular arena that could be navigated by foot. Equally spaced out (each 90° apart, placed at N, S, E & W), and attached to the curtain at eye height were 4 distal cues consisting of child-like drawings of a sun, a moon, some stars and a comet. These cues were painted using luminous paint, allowing them to be seen easily as the arena light was dimmed. Embedded underneath the carpeted surface of the arena were 20 magnetic capacity detectors, distributed across the circular arena and arranged in such a way that when viewed from any of the 4 distal cue positions, the arrangement of points appears the same (see figure 1 overleaf).

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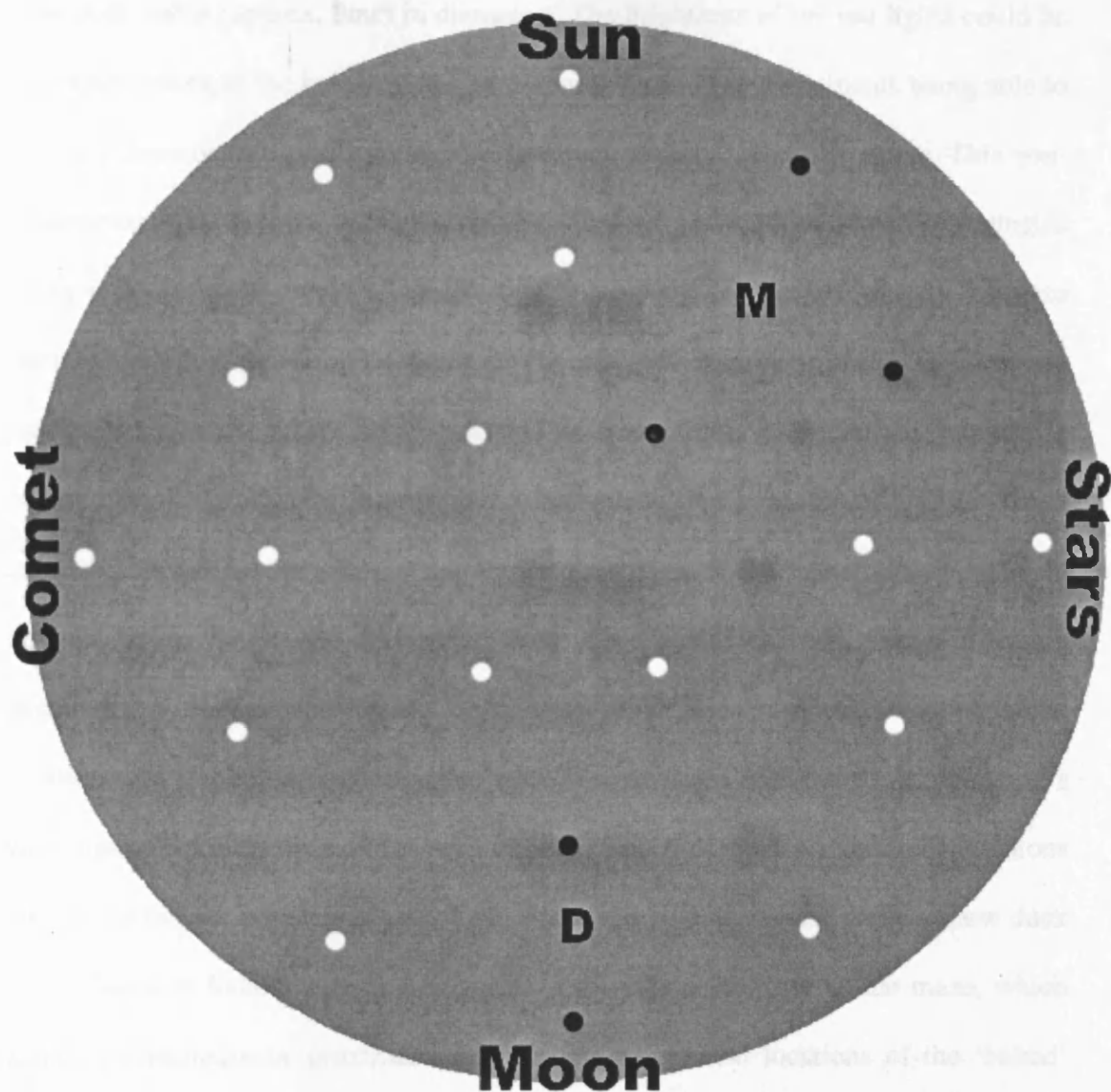


Figure 1 - Arrangement of stimuli on floor of the locomotor maze
 (Solid dots represent baited locations and white dots represent unbaited locations. Internal cues are M(ouse) and D(uck). Extramaze cues are labelled at the perimeter.)

These detectors measured ion concentration above them and sent a signal to a PC (in an adjacent room) as they were activated by a person standing at the corresponding position. In order for the location of these 20 detectors to be seen, the position was marked by a small point of red light on the surface of the carpet, as provided by a

fibre optic cable (approx. 3mm in diameter). The brightness of the red lights could be varied according to the height of the participant, resulting in participants being able to see only three or four positions at once from any location within the maze. This non-simultaneous viewing of the 20 locations aided in preventing geometric strategies being used to code the locations in space. Auditory feedback could be given to participants upon activating (standing on) one of the detectors, in the form of a tone, presented via loudspeakers situated outside the maze arena. All tones had frequencies of less than 40 Hz, preventing them from being localised in space and so being used as an additional spatial cue. In this experiment, five of the twenty locations were targeted to be in the 'to be remembered' set ('baited' to use animal literature terminology) and yielded a tone when stood upon. If a previously visited target location was stepped upon more than once (i.e. revisited within a trial, indicating a working-memory error), no tone was emitted. The non-target ('unbaited') locations also failed to emit a tone when stood on. Finally, a blue toy mouse and a yellow duck were placed in fixed positions (see figure 1 above) on the floor of the maze, which acted as intra-maze or proximal cues marking the general locations of the 'baited' targets.

The status of the 20 locations (i.e. whether standing on the sensor produced a tone or not) and the recording of visited locations was recorded and controlled by a standard PC computer.

(2) Virtual Reality Locomotor Maze (Same spatial configuration as real maze)

The VR version of the Kiel locomotor maze was constructed using Superscape's VRT 5 software. It was designed to replicate approximately the real maze in structure and function. The environment was a circular arena, made to scale and mimicked the

interior of the real maze. The 20 floor locations, represented by small red cubes, were arranged in identical positions to the 20 in the real maze (described above). A mobile moving human viewpoint (height 100,000 units, equivalent to 1.0 metres) was set up in the VR environment, allowing for locomotion through the virtual arena. The vertical field of view was 53.1 degrees and the viewing frustum intersected the floor at 240,000 units, equivalent to 2.4 metres. A horizontal field of view of 82.4 degrees was used. The cubes were programmed to be invisible at a fixed distance from the human viewpoint, resulting in only three or four being visible at any one time, the same as in the real maze. Red cubes became visible at a distance of approximately 200,000 units, 2 metres from the base of the human viewpoint. This was approximately the same distance at which the view frustum intersected with the floor. Two three-dimensional clip-art objects, a duck and a mouse, were imported into the virtual arena in positions equivalent to those occupied by the duck and mouse in the real maze (and also facing the same directions as those in the real maze). Four digitised copies of the distal cues (sun, a moon, some stars and a comet) were positioned on the perimeter walls again matching the positions of the distal cues in the real maze. The spatial configuration of the targets and cues in the virtual maze was therefore identical to the real locomotor maze and is therefore again represented in figure 1 shown earlier.

A joystick, that controlled the human viewpoint allowing the user to move forwards, backwards and rotate clockwise and anti-clockwise, controlled movement in the virtual maze across the arena floor. In order to activate a location in the virtual maze (i.e. choose a specific location out of the 20 possibilities) participants had to navigate towards the red cube using the joystick and then click on the cube using the mouse cursor. Only visible targets could be selected using the mouse and participants were

encouraged to 'walk right up close to the target'. This was the equivalent of standing on top of, and thus activating, a sensor in the real locomotor maze.

Auditory feedback was given via multimedia speakers located to the left and right of the PC monitor. If the cube clicked was an active or 'baited' location then a particular sound played, but if the cube was *not* one of the baited locations then a different and easily distinguishable sound was emitted from the speakers. Therefore all locations emitted a sound when selected, but two sounds were used, one to represent a 'correct' choice and another to represent an 'incorrect' choice. The 5 locations programmed to give the 'correct' sound when activated were the same as the 'correct' locations in the real maze.

(3) Virtual Reality Locomotor Maze (Different spatial configuration to real maze)

A second VR maze environment was constructed which was identical to the one described above except that the five active floor targets were rotated by 90 degrees, leading to a discrepancy between the positions of target locations in the virtual maze and the real one. The actual configuration of the targets remained the same, and it was simply their positions relative to the proximal and distal cues that changed. This environment was used in the 'incorrect VR trained' group described in the procedure below.

The virtual maze environment was run on a Pentium class multimedia PC attached to a joystick and displayed on a 19-inch colour monitor. Figure 2 below shows a screen shot from the actual program.

P.T.O



Figure 2 – Screenshot of the virtual maze as presented using the VRT software.

Procedure:

The procedure varied according to which of the three Training Groups and two Locomotion conditions participants had been assigned to.

The main aim of the task was for participants to identify the 5 correct locations on the floor of the *real* locomotor maze. They were required to do this until they reached a fixed learning criterion of 2 successive errorless trials, that is two successive trials correctly identifying the target locations with *no* returns to previously chosen targets and *no* selection of non-target ('unbaited') locations. One trial represented the time taken in the maze to identify and choose *all* 5 target locations.

Prior to being tested in the real maze, two of the three training condition groups were first trained to the same learning criterion as above but using the virtual reality maze described in the apparatus section above. The 'correct VR trained' group were trained in the VR maze of which the spatial configuration matched that of the real maze, and the 'incorrect VR trained' group were trained in the VR maze of which the spatial configuration was different to the real maze. The third group received no prior training in any virtual environment and were immediately exposed to the real maze.

Initial VR training procedure for VR trained groups:

In both groups children were introduced to the computer environment and the aim of the experiment was explained in the form of a “squirrel game”. The children were told that a squirrel was looking for nuts for winter and that they were going to help. They were shown how to use the joystick to look around and how to click a cube with the mouse to determine whether or not a nut was hidden there. In the first trial, they were allowed to move around, clicking on the cubes to work out where the nuts were found. During this process the experimenter informed them when they were correct and when they were not, so that they could learn to distinguish between the “correct” and the “incorrect” sounds emitted from the computer speakers. They were also verbally informed when they made re-visits to locations that they had already explored in that trial. Once they had found all 5 baited locations the environment was re-loaded and another trial started. They were trained on this search task until they had reached a learning criterion, set as two consecutive trials made with no error visits to non-baited locations and no re-visits to baited ones. Having reached the learning criterion, participants were taken to the real locomotor maze where they completed the procedure described below.

Real locomotor maze procedure:

Individual children were introduced to the maze. All participants were allowed to familiarise themselves with the layout of the maze, including the proximal and distal cues. They were then given a switch to darken the maze and at this point some of the red lights on the carpet could be seen for the first time. Children who had been given prior training on the VR maze were told that this was the same maze that they had been playing with earlier on the computer. Those who had been given prior training

were asked again to “...try and find and visit *only* the hiding places containing the nuts, that is, the ones with the tone.” They were asked to do this until they reached the learning criterion used in the VR version (2 successive errorless trials).

For those children who had not received any prior VR training the squirrel story (see VR training procedure above) was explained to them and they were then allowed to search for the “hidden nuts” until they too reached the learning criterion of 2 successive errorless trials.

During the above procedure, the experimenter moved about the maze so as to not provide an additional intermaze spatial cue, and also counted out loud the number of correctly identified baited locations. Prior to the acquisition trials, children were allowed one trial (exploration trial) to freely explore the maze and floor targets and this exploration was terminated when all five baited targets were chosen (irrespective of how many non-baited locations were visited).

Procedure in real maze for the two exploration groups

The search method in the real maze varied according to whether participants had been assigned to the active or passive exploration group. Half of the participants were randomly assigned to the active exploration condition, in which they physically walked around the maze and stood upon the chosen targets. The other half, assigned to a passive condition, were sat on a chair in the maze and were asked to point out, using a laser pointer, which locations the experimenter should step on. The floor lights were turned up so that all of them could be seen from the child’s position. As the laser pointer pointed out each position, the experimenter activated the sensor for that location. In order to prevent the experimenter from being used as an intermaze cue,

the experimenter would move about the maze during the spaces between choosing locations.

To finish, all participants were given one last trial in which a 180° rotation of the proximal cues (the robot and the duck) was implemented, along with the entry position to the maze also being rotated by 180°. This led to a conflict between the previously learnt target locations with respect to the distal cues and the new spatial information. After their experience in the maze participants were quizzed about their use of three-dimensional computer games.

5.2.2 Results

The data from this experiment was analysed using non-parametric statistical procedures because of the small sample sizes and non-normal distribution of the scores.

Initially the data were analysed with respect to the two locomotor groups (active vs. passive). A Mann-Whitney U test was executed on these two independent groups and revealed no difference in the number of trials needed to reach criterion in the real maze [$U = 565.0$; $p > 0.05$]. The same test was run on the mean error data (total number of error revisits) and showed no significant differences between active and passive sub-groups [$U = 597.5$; $p > 0.05$]. For the further analyses, active and passive sub-groups were therefore pooled.

Next, the average number of locations visited during the exploration trial was compared across the training group variable (correct VR training, misleading VR training & no VR training). The results are summarised in figure 3 (see section 5.4 - appendix). A Kruskal-Wallis test highlighted a main effect for training group [$H =$

46.29, $df = 2$, $p < 0.01$] which was followed up by Mann-Whitney U tests. No sex differences were seen during the exploration phase and so data for males and females were again pooled. All three paired comparisons differed significantly. The group given incorrect VR training made significantly more visits to locations than the other two groups [incorrect training vs. no training; $U = 177.0$, $p < 0.01$ & incorrect training vs. correct VR training; $U = 7.5$, $p < 0.01$]. The correct VR training group made fewer visits than the no training group [$U = 14.5$, $p < 0.01$]. Next, data from the acquisition trials were analysed.

The average number of trials required to reach criterion (two consecutive errorless trials) were analysed. Figure 4 (Section 5.4) summarises the findings. A main effect for training group was discovered [$H = 36.09$, $df = 2$, $p < 0.01$ {Means (SEM): VR-2.46 (0.23), incor VR-4.21 (0.29), no VR-6.38 (0.55)}] which was followed up by Mann-Whitney U tests. Participants given no training required more trials to reach criterion than those given incorrect VR training, and both these groups required more trials, on average, than the correct VR trained group. [cor VR vs. no VR ($U = 33.0$, $p < 0.01$); cor VR vs. incor VR ($U = 78.0$, $p < 0.01$); incor VR vs. no VR ($U = 144.5$, $p < 0.01$)]. Three Patel-Hoel tests [a distribution free (non-parametric) statistical test, see Krauth (1989)] were used to examine the data for a gender by training group interaction. A sex difference was only apparent in the misleading VR trained group [$Z = 2.59$, $p < 0.05$]. This can be seen on the middle 2 bars of figure 4 (Section 5.4) with males performing significantly better than females.

Next, the total number of error revisits (mean sum of errors) were examined for differences between groups and also for sex differences. A main effect for training group again emerged [$H = 33.48$, $p < 0.01$ {Means (SEM): VR-0.68 (0.41), incor VR-5.52 (1.12), no VR-7.40 (0.90)}], and the further analysis highlighted a difference

between scores for both the incorrectly trained VR group and the non-trained group compared to the correctly trained VR group [$U = 69.0, p < 0.01$ & $U = 35.5, p < 0.01$ respectively]. Interestingly, no significant difference was found on this measure between the incorrectly trained VR group and the non-trained participants [$U = 208.5, p > 0.05$]. A sex difference was again found in only the incorrect VR training group, with males making fewer errors than females [$Z = 1.98, p < 0.05$]. These findings are displayed in figure 5 (Section 5.4).

The times between successive choices of floor targets [Inter Response Intervals (IRIs)] were also examined statistically. No sex differences were observed, but training group differences were seen [$H = 20.13, df = 2, p < 0.01$]. The accurately trained VR group made faster responses to targets than the non-trained group [$U = 14.0, p < 0.01$]. The group given incorrect VR training differed from both the non-trained group [$U = 177.0, p < 0.05$] and the correct VR trained group [$U = 163.0, p < 0.01$]. Figure 6 (Section 5.4) presents these findings graphically.

Next, performance over time (across trials) was examined by plotting learning curves for the three training groups. Figure 7 (Section 5.4) shows the mean number of choices per trial for each of the groups (Non trained, VR trained & Incorrectly VR trained). Most participants had reached the learning criterion (2 successive errorless trials i.e 5 choices in a trial, all of which were correct) by trial 7 and so the data from trial 8 onwards only really represent one or two participants and has been cut from the graph. The means were calculated from unequal n values, as the number of trials varied per participant, some reaching the learning criterion earlier than others.

The non-trained group had the highest mean number of choices per trial initially and then displayed a typical learning curve with performance increasing over trials 1-6 and then reaching a plateau. The incorrectly VR trained group made fewer choices but

still showed a learning curve, reflecting the need to re-learn the locations of the baited targets. The curve parallels the learning curve for the untrained participants. Thirdly, the group previously given correct VR training showed a more or less flat line, suggesting that little learning is required when transferred to the real maze. This indicates that the locations of the baited targets have been learnt in the VR maze and successfully transferred to the real maze, without any re-learning phase necessary.

When the three groups of participants were tested on the cue-rotated environment, none of the groups differed significantly (error scores measured), with all groups displaying equal spatial competence [$H = 1.35$, $p > 0.05$], and with no observable sex differences.

Finally, the data presented in figure 8 (Section 5.4) suggests that those participants who had experienced 3-D computer games (e.g. Doom, Heretic and other such games) performed better, in terms of making fewer errors during the acquisition phase, than those who had not had such experience. However this was a general tendency which was not found to be statistically significant [$U = 199.5$, $p > 0.05$].

5.3 Discussion

The principal finding of this study is that information learnt in a virtual locomotor maze can be transferred to a real version of the maze. This is consistent with the findings of numerous studies, which have shown that information can be transferred from virtual environments to the real world [Mowafy & Pollack (1995), Cromby, Standen, Newman & Tasker (1996), Standen and Low (1996), Wilson, Foreman & Tlauka (1996), Wilson, Foreman & Tlauka (1997), see also Stanton, Foreman & Wilson (1998)]. With regards to active versus passive learning, no effects on performance were observed, suggesting that physical locomotion is not necessary for

place learning. These results are consistent with the findings reported by Wilson et al (1997) and Wilson (1999).

In this study transfer of information was reflected by lower number of locations visited, lower mean sum of errors, lower number of trials to reach criterion and shorter inter-response intervals for those participants who were trained on the correct VR maze simulation compared with those who received no VR training. In the case of those participants who were given misleading VR training, incorrect spatial information was clearly learnt from the virtual version, which participants then tried to apply to the real locomotor maze. However, because this information was not consistent with the actual positions of the correct targets this led to confusion in participants (i.e. their cognitive map of the environment did not match the real one) resulting in a significantly higher number of visits to locations than either the VR trained or the untrained groups. The difference between the incorrectly VR trained group and the untrained group was probably due to participants having to update their existent cognitive map [O'Keefe & Nadel (1978)] that was created during the inconsistent VR training period. This mismatch between map and territory indicates that the configuration of targets and cues need to be re-learnt in order to perform the task correctly. This re-learning results in performance of the incorrectly trained participants being worse than those who received no prior training.

Examination of the trial data presented in figure 7 further supports the evidence for transfer of information from virtual to real. Both the incorrectly VR trained and the non-trained groups show a learning phase during the real maze trials. However the correctly VR trained group do not show a learning period when transferred to the real maze thus it is suggested that the required spatial information has *already* been acquired in the VR version and has been successfully applied to the real locomotor

environment. The presence of a learning curve for the incorrectly VR trained group strongly suggests that a period of re-learning is required to solve the task at hand.

The misleading (incorrect) VR training condition is useful as it suggests that it is 'spatial' information that is being transferred as opposed to other less specific factors such as environmental familiarity (familiarity with cues and lights). In terms of the average number of trials required to reach criterion (figure 4), the incorrectly VR trained group required more trials than those given correct VR training, who required less trials than the un-trained group. These results clearly suggest that VR training, even if it is incorrect, benefits performance in the real locomotor maze. This suggests that perhaps environmental familiarity and other non-specific factors do play a role and are also transferred from virtual to real as well as spatial information.

However, when the results were examined with respect to the mean sum of errors made, a different pattern emerged, with no difference between the untrained and the incorrect VR-trained groups. The targets that participants in the incorrectly trained VR group were trained to recognise as baited were not randomly distributed across the 20 locations but instead were rotated through 90° with respect to the distal cues (environmental frame of reference). Correct completion of the task could therefore be accomplished by rotating the target configuration held mentally and applying it to the real maze. This may explain how even incorrect VR training was beneficial to some degree. It would be interesting to observe whether more disruption occurs when the participants are trained to a completely randomly arranged configuration of target and non-target locations.

When sex differences were examined differences were only seen in the incorrectly trained VR group (see Figures 4 & 5). As discussed above, the mistrained group can apply a mental rotation to solve the task and such abilities have been commonly found

to differ between males and females [see Voyer, Voyer & Bryden (1995)]. Poorer performance in females is reflected in this study, with females in the incorrectly trained condition performing worse than males on measures of average number of trials to reach criterion and mean sum of errors.

Finally, the results showed a tendency for participants with previous 3-D gaming experience to make fewer errors, however the difference in performance was not statistically significant and therefore cannot be considered an additional factor that effects performance.

The VR environment described in this chapter was the first prototype of it's kind and is being improved upon by computer programmers in Kiel, Germany. This initial VR simulation differs from real experience of the maze in a few ways. A human viewpoint was used, which did not allow the user to look down at their feet and selection of a target was done by the clicking of the mouse. Amendments are underway which allow the user to see their virtual self in the environment. The user can look down towards their feet and then virtually step onto a target in the same way as activating a sensor in the real maze. The virtual version of the maze is also being programmed to record data in the same way as the real maze including recording response patterns and inter-response intervals.

Once the VR maze has been further developed it can be used to test place finding behaviour in a wide variety of participants, particularly those with neurological damage e.g. Alzheimer's, Parkinson's. The virtual version of the maze can be easily set up and run in a patient's home or in clinics. The VR maze will also be useful in examining spatial behaviour of people with physical disabilities who would find it difficult or impossible to navigate physically through the relatively small area in the real maze and for those groups of participants who have mobility difficulties, such as

the elderly. Interaction with the software might be a problem for this group, but a training environment could be built that would allow the joystick skills to be perfected.

In conclusion, this study has shown that spatial skills learnt in a virtual locomotor maze are effectively transferred to the real version, suggesting that a VR simulation of the maze can be used on it's own to explore spatial processing in humans. Non-spatial elements of a task may also be transferred and males outperform females when a spatial rotation task is required.

5.4 Appendix

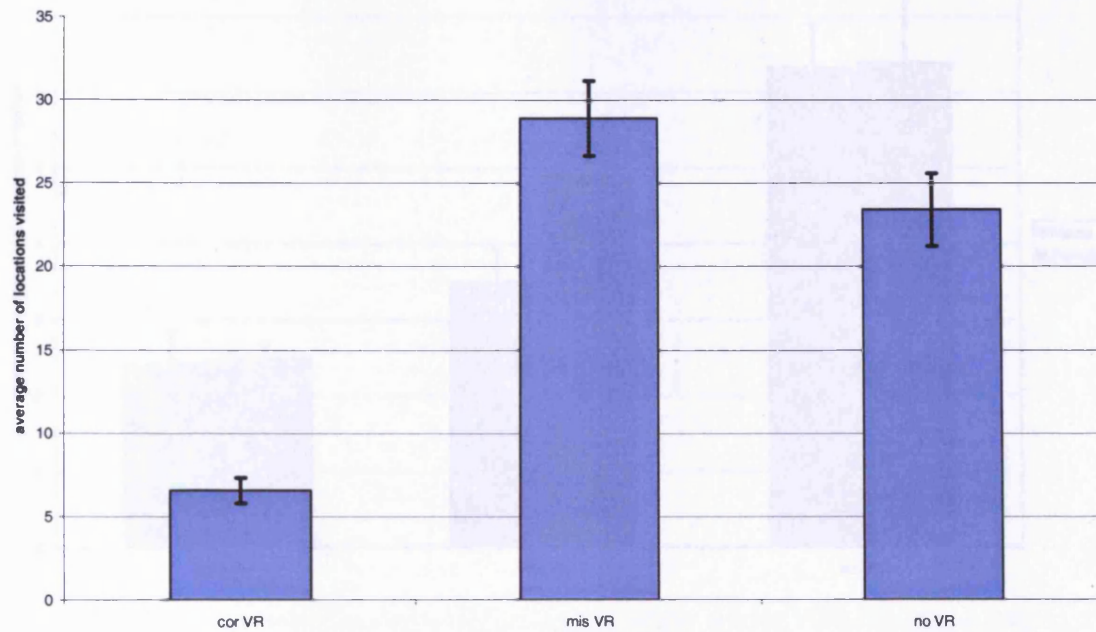


Figure 3 - Exploration of the Kiel locomotor maze under different training conditions

(Bars represent mean number of locations visited & Error bars represent one standard error of the mean)

cor VR = correct VR training

mis VR = misleading (incorrect) VR training

no VR = no VR training

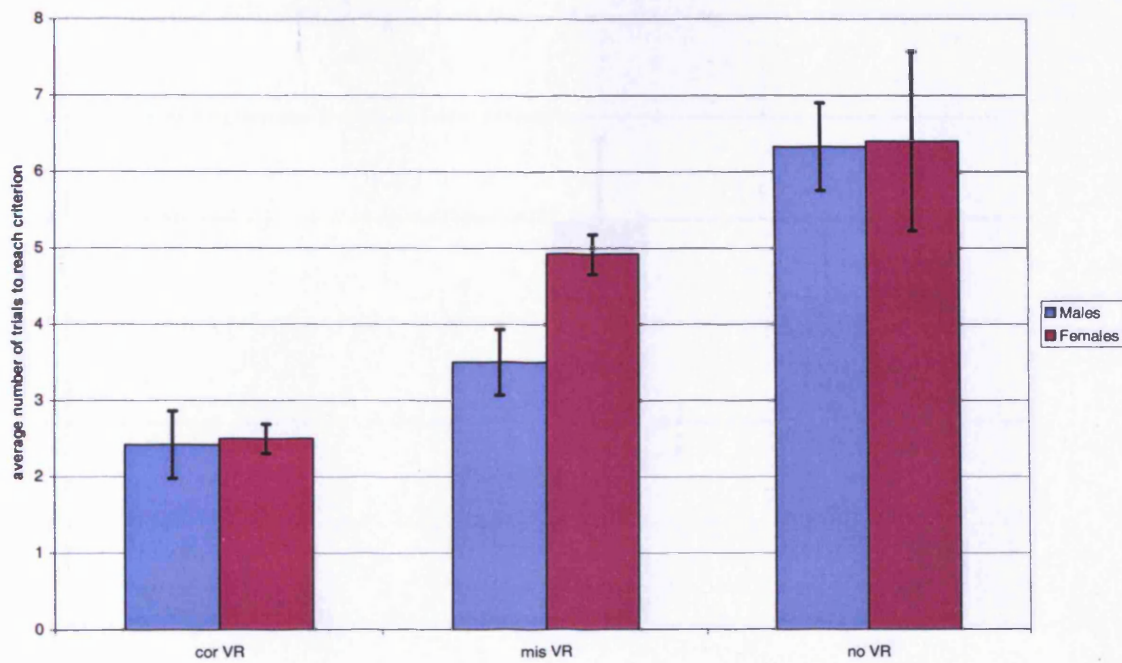


Figure 4 – Learning in the Kiel locomotor maze under different training conditions

(Bars represent average number of trials to reach criterion for both males and females
& Error bars represent one standard error of the mean)

cor VR = correct VR training

mis VR = misleading (incorrect) VR training

no VR = no VR training

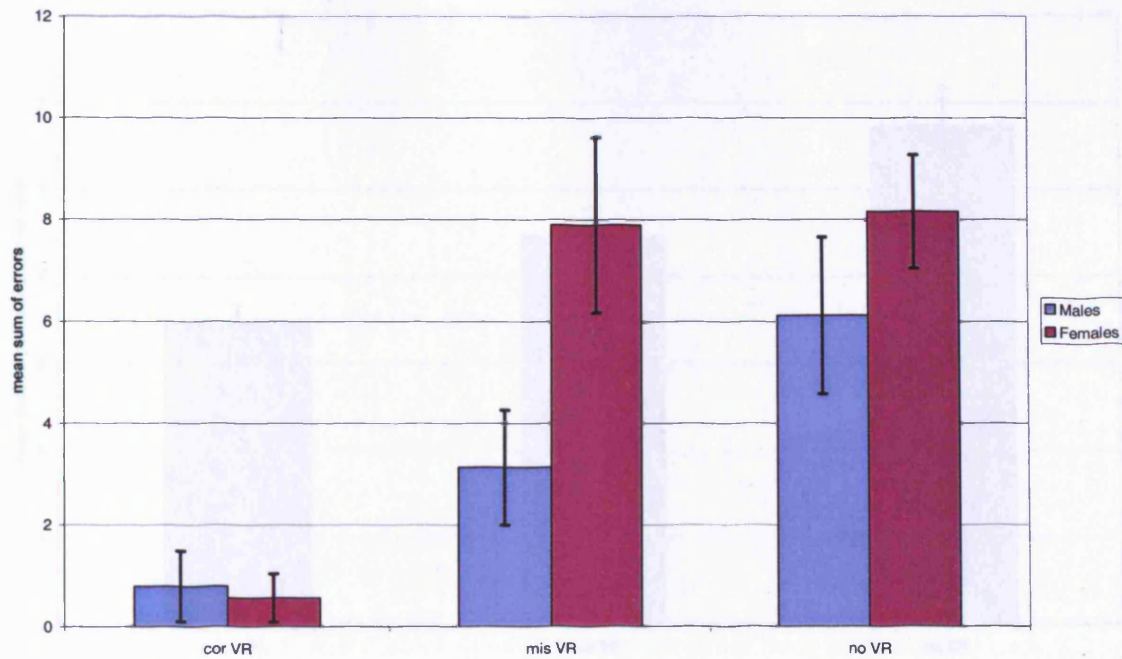


Figure 5 – Learning in the Kiel locomotor maze under different training conditions

(Bars represent the mean sum of errors for both males and females & Error bars represent one standard error of the mean)

cor VR = correct VR training

mis VR = misleading (incorrect) VR training

no VR = no VR training

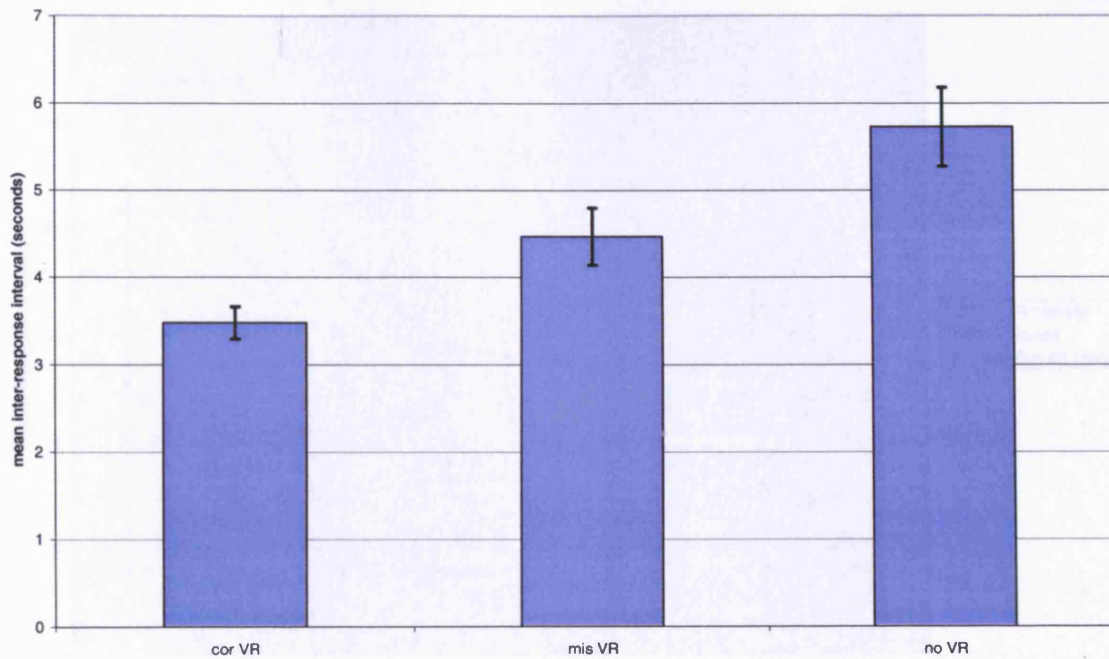


Figure 6 – Learning in the Kiel locomotor maze under different training conditions

(Bars represent the mean inter-response intervals & Error bars represent one standard error of the mean)

cor VR = correct VR training

mis VR = misleading (incorrect) VR training

no VR = no VR training

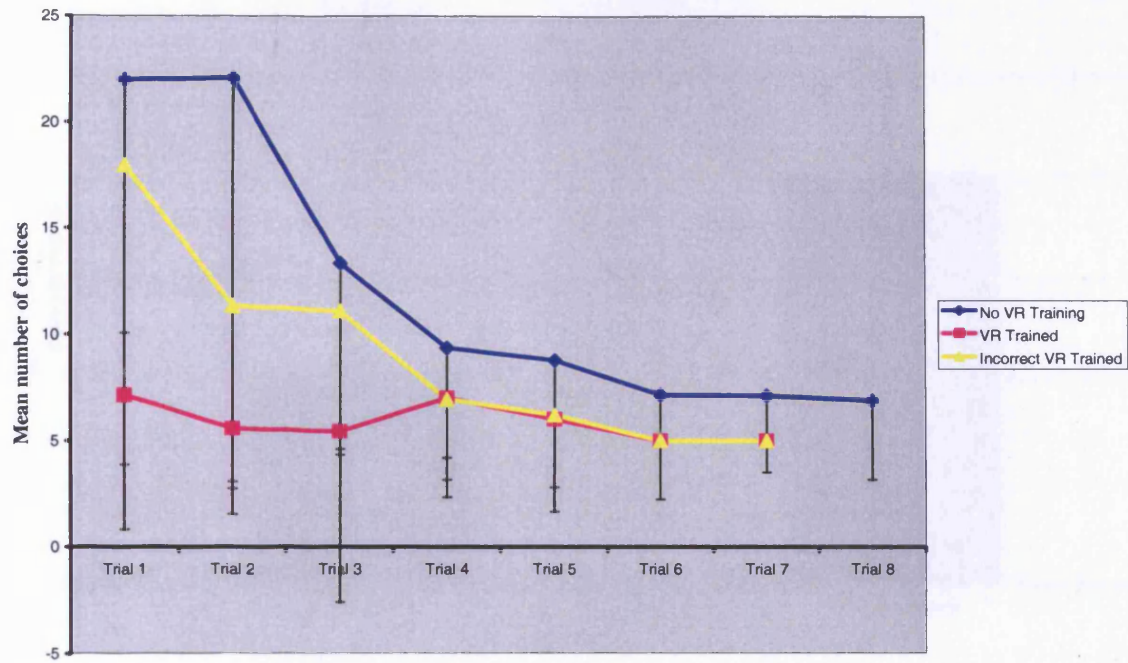


Figure 7 – Performance of different training groups across trials in the Kiel locomotor maze (data from trial 8 onwards for non trained group removed, whiskers represent -1 standard deviation)

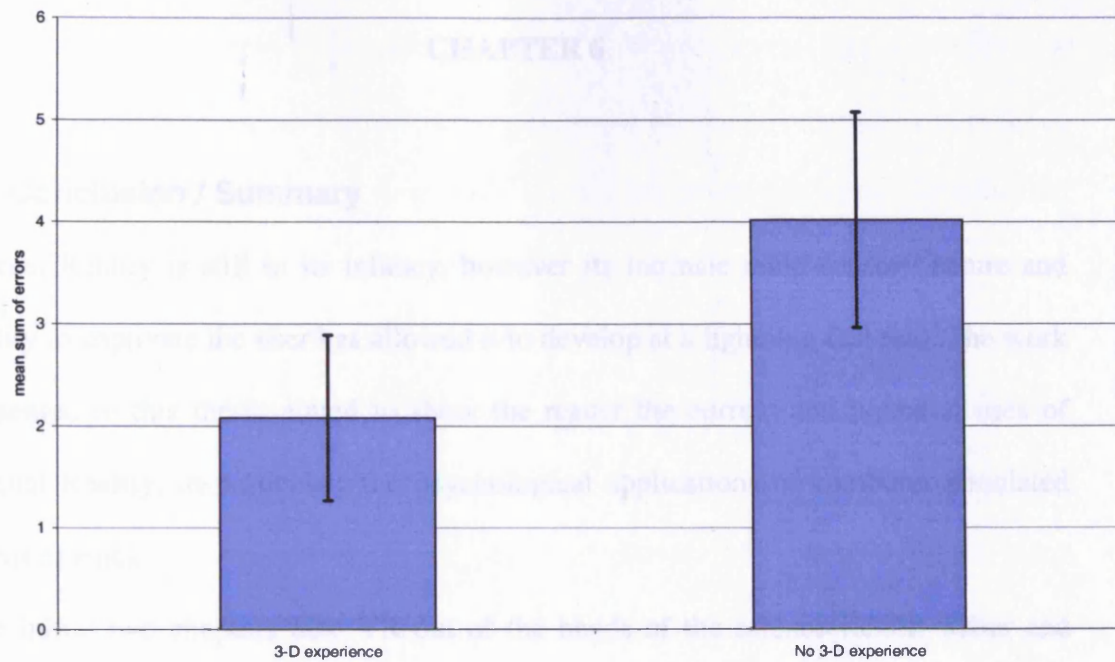


Figure 8 – Learning in the Kiel locomotor maze according to previous 3D experience

(Bars represent mean sum of errors & Error bars represent one standard error of the mean)

CHAPTER 6

6.1 Conclusion / Summary

Virtual Reality is still in its infancy, however its intrinsic multi-sensory nature and ability to captivate the user has allowed it to develop at a lightning fast rate. The work presented in this thesis aimed to show the reader the current and potential uses of Virtual Reality, in particular, the psychological applications of computer simulated environments.

The initial two chapters take VR out of the hands of the science fiction writer and place it firmly within a scientific and educational framework. These chapters introduced the reader to what virtual reality is and some of its' current applications in a broad range of areas, including medicine, education, art and the gaming industry. As well as defining VR, Chapter 1 described the software (Superscape VRT) used to design the experiments which are presented in the latter section of the thesis. VR design software continues to be developed, and the future offers even more realistic environments that can be used in psychological evaluation. Furthermore display devices and interfaces are continually being researched and improved. This continuing improvement in technology aims to decrease the potential risks and side-effects of VR immersion, which were also discussed, allowing ethical issues associated with immersive VR testing of patient groups to diminish. Because of both ethical and technical problems related to immersive environments, all of the environments presented to participants in this work were non-immersive (desktop) in nature.

Chapter 2 extended the range of uses of virtual reality to the psychological domain and discussed its clinical applications. This chapter examined traditional clinical approaches to measuring spatial ability, whilst summarising some well-documented

clinical spatial disorders in human patients. The chapter further discussed the two classical animal paradigms, which formed the basis for the experiments presented in later chapters. It is clear that virtual environments can be used to assess neurological damage and to examine elements of spatial cognition in humans. The remaining sections of the chapter focused on a number of issues relating to spatial cognition in virtual environments, including similarities and differences between real and virtual worlds, transfer of training and large versus small-scale spaces. Many studies were discussed which provide examples of previous research into spatial cognition using VEs.

Chapter 3 focused on the use of virtual environments to assess the consequences of neurological damage in clinical patients. The experiment presented therein looked at patients with Parkinson's disease and those who had suffered closed head injuries (CHI). Both the virtual environments included features which would have been difficult, if not impossible, to include in a real world testing procedure. For example, the flag task allowed the user to switch instantly from one point of view to another, without the need to navigate from one place to the next. The tray task provided the participants with a fixed perspective of the objects, which was not affected by their own head or eye movements. This high-level control of the testing environment is one of the major advantages of VR assessment compared with traditional neuropsychological approaches. The results of this study suggested that some VR tasks are more sensitive to visuospatial deficits than others and that CHI patients clearly show poorer performance on spatial VR tasks. Early stage Parkinson's patients did not exhibit spatial deficits on one of the VR tests, suggesting that perhaps only specific spatial skills deteriorate in the early stages of the disease. Virtual reality assessment procedures have a lot to offer the clinical community, however further

integration and collaboration between clinicians and experimental psychologists is necessary to fully examine the potential of this technology.

Chapters 4 and 5 turned the reader's attention to the uses of VR to examine pre-existing psychological theories, most of which had been initiated from animal studies, and then to investigate transfer of training. All of the studies presented in these chapters were based upon variations of animal paradigms that have been used to examine aspects of spatial cognition in rats. The two major paradigms are the radial arm maze and the water maze.

The two experiments presented in Chapter 4 used virtual reality environments to examine the differential use of cue information to solve a multiple goal task. They examined the importance of distal (extramaze) and proximal (intermaze) cues in establishing a cognitive map of an environment and found that the results supported the general research findings that distal cues are used more frequently in place learning tasks. Sex differences were also suggested, but the findings were inconsistent across the two experiments. These two experiments again used unique features of VR to manipulate the cue configurations and to instantly remove sub-sets of cues.

The experiment discussed in Chapter 5 was carried out to determine whether spatial learning in virtual environments is equivalent to that in the real world. For VEs to be useful in psychology, we need to know that spatial information is processed in a similar way to the spatial concepts that exist in the real world. Transfer of learning studies have been of particular concern to those who use VR to train specific skills, but they are equally important to psychologists who wish to design VR testing procedures. It is important to know that a VR spatial test is measuring the same cognitive skill(s) as the equivalent real world version. If learning in a VR world is inconsistent with learning in real life situations, then VR has no place in psychology

as an alternative testing medium. Previous research, plus the study presented in Chapter 5, shows that skills learnt in a virtual environment do successfully transfer to the real world task. Transfer of spatial information was demonstrated using a virtual version of the Kiel locomotor maze. This study also found that females perform worse when a solution to a spatial problem requires a mental rotation element.

In conclusion, this thesis has hopefully shown the reader that virtual reality is more than just a toy and that it has a great deal to offer psychologists and educators. It can be a useful alternative tool, which can be used by researchers to implement neurological assessment and aid the advancement of current psychological theories of human spatial cognition.

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